BUILDING CONSTRUCTION.

ADVANCED AND HONOURS.

BUILDING CONSTRUCTION

A TEXT BOOK ON THE PRINCIPLES AND DETAILS OF MODERN CONSTRUCTION

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STAGES 2, 3 AND HONOURS

(ADVANCED AND HONOURS COURSES)

Compiled to assist Students preparing for the Examinations of the Board of Education, the Royal Institute of British Architects, the War Office, the Surveyors' Institution, the City Guilds, the Civil Service, and other Examinations.

Fifth Edition, thoroughly Revised and much Enlarged.

(THIRTY-THIRD THOUSAND.)

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PREFACE

TO THE FIFTH EDITION.

In this edition an endeavour has been made not only to more fully satisfy the requirements of the latest Syllabuses in Building Construction of the Board of Education and other examining bodies, but at the same time to make the work of even more use than hitherto to those engaged in actual practice.

The fortunate coincidence of a simultaneous call for new editions of this and the Author's "Elementary Course" has afforded the opportunity of revising the work in a more thorough manner than would otherwise have been possible. Each Course has been considered in relation to the requirements of the stages dealt with, and thus each may now be said to be the complement of the other.

A thorough revision of the work has been rendered all the more necessary on account of the great progress that has taken place during the past few years in the science of construction and in the direction of the standardization of materials.

It will be observed that the chapters relating to Materials, Brickwork, Masonry, Vaulting, Graphic Statics, Steel Construction, Joinery and Staircasing, Roofs and

Roof Coverings, have been decidedly extended, and in the majority of cases recast, with the addition of many new illustrations; while a new chapter on the important subject of Ferro-Concrete Construction has been inserted. The calculations throughout the book have been modernised and simplified, and the author is glad to be able to include the important specifications of the Engineering Standards Committee relating to Portland Cement and Structural Steel Work, and British Standard Sections.

He desires to take this opportunity of thanking the many specialists who have afforded valuable information and otherwise assisted in the revision of the work, and to the publisher for generous suggestions and help.

Special thanks are due to the author's colleagues, Mr. F. E. Weston, Hons. B.Sc., and to Mr. W. Hibbert, F.I.C., for their generous revision of the Chemical and Electrical portions of the work.

In conclusion he hopes this edition will enjoy an increased measure of the approval so widely accorded to the previous issues by both teachers and students.

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LIST OF WORKS, ETC.,

REFERRED TO.

In preparing this treatise the author is pleased to acknowledge his indebtedness to the authors of the following works which he has consulted :—

"Chemistry of Building Materials" ... ... Abney.
"Chemistry" (Matriculation) ... ... Bailey.
"Gothic Architecture" ... ... Bond.
"Graphic Statics" ... ... G. S. Clarke.
"Plumbing Practice" ... ... Wright Clarke
"Modern Practical Joinery" ... ... Ellis.
"History of Architecture" ... ... Fletcher.
"Quantities" ... ... Fletcher.
"Iron and Steel" ... ... Greenwood.
"Vectors and Rotors" ... ... Henrici.
"Architectural Surveyors' Handbook"... ... Hurst.
"The Engineers' Year Book of Tables, Data, and Memoranda, 1906" ... ... Kempe.
"Model Bye-Laws" ... ... Knight.
"Quantity Surveying" ... ... Leaning.
"Building Specifications" ... ... Leaning.
"Reinforced Concrete" ... ... Marsh.
"Plastering, Plain and Decorative" ... ... Millar.
"Pocket Book of Engineering Formulæ" ... Molesworth
"Ferro-Concrete" (Hennebique) ... ... Mouchel.
"Concrete, its Use in Building"... ... ... Potter.
"Applied Mechanics" ... ... Rankine
"Civil Engineering" ... ... Rankine
"How to Estimate" ... ... Rea.
"Notes on Building Construction" ... ... Rivington.
"Builders' Work" ... ... Seddon, Col H.
"Concrete" ... ... Sutcliffe.
"Carpentry Workshop Practice" ... ... Mitchell.
"Concrete Steel" ... ... Twelvetrees.
"Testing of Materials of Construction" ... Unwin.
"Instruction in Construction" ... ... Wray, Col. H.
Board of Education Examination Papers.
The "Builder."
The "Building News."
The "Builders' Journal."
Publications of the London County Council.
Building Laws of the New York City Council.
Publications of the R.I.B.A.
Publications of the Engineering Standards Committee.

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ADVANCED AND HONOURS BUILDING CONSTRUCTION.

CHAPTER I.

MATERIALS.

LIMES AND CEMENTS.

Limestones.—Stones consisting entirely or in a great part of carbonate of lime, $CaCO_3$, are known as limestones, and are quarried chiefly in the form of chalk, which is a soft white rock of almost pure calcium carbonate, limestones, and marbles. For descriptions of the latter two, see Chapter on Stones.

The resultant of limestones after burning is lime, the latter is used in building operations (*a*) as a matrix for concrete, (*b*) in the preparation of mortar for bedding bricks or stones in walling, and (*c*) as a cementing material in the plaster used for the covering of walls.

Classification.—Limes are classified under the following heads:—

1. Pure or rich limes.
2. Poor limes.
3. Hydraulic { Feebly hydraulic / Hydraulic. / Eminently hydraulic. }

Limestones are never found absolutely pure in nature,

but are either mixed with impurities or in combination with them, which impurities, if soluble in acids, are useful in accelerating the setting action, but if insoluble in acids are valueless for that purpose.

Rich Limes.—Limes are said to be rich or pure when the impurities insoluble in acids do not exceed 6 per cent. of the whole mass.

For plastering, rich, pure, or fat limes only should be used, because of their readiness to slake, and their consequent non-liability to blister as compared with hydraulic limes.

Poor Limes are those containing from 15 to 30 per cent. of impurities insoluble in acids. They possess the general properties of rich limes, but in a less degree. They take longer to slake, and do not increase in bulk to such an extent as the rich limes. They do not take such a large ratio of sand, owing to the foreign matter they already contain.

Hydraulic Limes contain a quantity of combinable substances other than lime, such as silica and alumina, which on being burnt form calcium aluminates and calcium silicates, together with a portion of lime, the measure of these bodies up to a certain point being the measure of the hydraulicity. These bodies render the limes independent of external agents for their setting properties.

Limes containing 6 to 16 per cent. of these useful substances are termed feebly hydraulic, those 16 to 26 per cent. hydraulic, and those from 26 to 36 per cent. eminently hydraulic.

Hydraulic limes only should be used as the matrix for lime concrete, and they are most suitable for constructional work.

From the time limestone is quarried to the setting of

the lime in the work, four processes are performed, viz., burning, slaking, mixing with sand, and setting.

$CaCO_3$ is a substance insoluble in pure water, and is unable to combine with carbonic-acid gas when in this form, but is rendered suitable by calcination, which drives off the carbon dioxide (CO_2), leaving calcium oxide (CaO) together with any other impurities contained in the stone.

Burning of Limestones.—Limestones are burnt in kilns of various shapes, the most common being a cylindrical brick or stone casing lined with fire-brick, having a draw-hole at one part to apply the fuel; this arrangement is termed a flare kiln. A rough dome is built with the limestones, forming a chamber to contain the fire; the kiln is then filled about the dome, the top of the kiln being usually covered by a shed to protect it from the weather.

In burning the limestones, the heat should be applied gradually, otherwise the separation of the carbon dioxide from the stones takes place with such rapidity that they crumble to pieces.

It is imperative that the calcined stones should be withdrawn from the kiln as soon as the carbon dioxide has been driven off, this being determined as follows:—While any carbon dioxide remains in the stones they will be of a dark red colour, but when this gas passes off the colour changes to a brilliant white glow; at this point the stones should be withdrawn, or they will be overburnt, the result being limes very difficult to slake, this action often not taking place in some of the particles for a considerable time after being used for building purposes, this renders the limes unreliable for use, as they may blow when bedded in the work. A somewhat similar result occurs with underburnt limes.

Slaking.—The object of slaking lime is to form a calcium hydrate, thus rendering it quickly in a fit condition to

readily combine with the CO_2 to form crystals of calcium carbonate, the formation of the latter being a necessary condition for strength in a mortar. Slaking is induced by adding water to quicklime; these on combining give off great heat, which generates steam, causing the lime to expand, burst, and disintegrate with a series of small explosions forming a calcium hydrate, $Ca(OH)_2$, a whitish-yellow powder. The slaked lime thus formed is soluble, and hence when more water is added some of this dissolves and forms a saturated solution.

The soluble lime in a saturated solution is ready for the absorption of CO_2, which always exists in the atmosphere.

If quick-lime be left exposed to the air, it absorbs CO_2, which under these conditions renders it inert, as the resulting carbonate is not crystalline.

Slaking is an important process in the manufacture of mortar, and it is imperative that every particle of quick-lime must be thoroughly slaked, for if any unslaked portions are built in the work it will by its subsequent expansion disturb the rest of the work.

To obviate this failing, the mortar after mixing should always be kept for at least fourteen days before being used.

Sand is a form of silica (SiO_2); it is added to lime in the preparation of mortar, (1) to counteract the excessive shrinkage that takes place with pure lime mortar, (2) to assist in the crystallization by forming ducts through which the necessary CO_2 can have access and act upon the particles behind the surface, and (3) to increase the bulk of the mass (sand being much cheaper than lime).

The sand for mortar should be free from all earthy or clayey matter; it should have sharp angles and a rough surface.

The best sand for building purposes is that known as pit

sand. The next in order is river sand, which is obtained from the banks and beds of rivers; this kind is not considered so good as pit sand, the grains being rounded and worn smooth, the adhesive value being thus reduced. River sand is, however, largely used for plasterers' work, it being fine and of a light colour. The grains in sea sand are similar to river sand, round and smooth. Sea sand should never be used for plastering or other building work, as it effloresces, thereby causing a wall to be damp for a considerable time.

Sand should be fine for plasterers' work, and moderately coarse for bricklayers' work; it is usually screened and sometimes sifted to remove any large stones or shingle that it may contain.

Loamy or dirty sand should be washed before being used. This is usually effected by placing the sand in a vessel through which a stream of water is constantly passing, the sand at the same time being agitated to separate it from the foreign matter, which latter becomes suspended in the water and passes off.

Sand for all coats of plasterers' work is better washed, although for the first coats this is often neglected.

Setting of Lime.—The setting of lime depends on the absorption of CO_2 from the atmosphere by the particles of slaked lime in solution in the mortar, the carbon dioxide being soluble in water. The $Ca(OH)_2$ with excess of CO_2 combine to form $Ca(HCO_3)_2$ on evaporation, which decomposes into crystals of $CaCO_3$, the H_2O helping to dissolve the next particle, forming it into a saturated solution, and putting it into a condition to take up a molecule of CO_2; this in its turn repeats the already described action, and crystals of $CaCO_3$ are formed. The crystals always have a tendency to adhere to something rough and hard, such as sandy particles or the surfaces of bricks; for this

reason the addition of sand up to a certain ratio increases the strength of the mixture, the best ratio being one part pure lime to one of sand, the maximum being one of pure lime to three parts of sand.

A long time elapses before pure limes harden, owing to their depending upon external aid to attain this state. If lime alone were used the surface would set and form an impervious layer, and so check the CO_2 from acting on those particles below the surface, the moisture in which evaporates and leaves it in the state of a powder; and even when a large proportion of sand is used and the mass made porous, the supply of CO_2 must necessarily be small, and a long time elapses before the material hardens. Pure lime mortar built in thick walls never hardens nor sets, but crumbles into a friable powder.

For this reason pure limes should be avoided for constructional work, and a lime or cement which does not depend on external aid to set, be used.

Setting of Hydraulic Limes and Cements.—The setting of hydraulic limes and cements is due chiefly to the formation of crystals of hydrated calcium silicate and hydrated calcium aluminate, and a typical Portland cement would be represented somewhat as follows:—

$$(CaO)_2 . Al_2O_3\ H_2O + 3\ (2\ CaO, SiO_2\ H_2O)$$

and in hydraulic limes to a certain extent to the absorption of CO_2, there being in most of these a small percentage of free lime.

As these limes and cements do not depend on external agencies for their setting properties, they are able to set in the centre of thick walls and under water. This renders them valuable for all constructional work.

Hydraulic limes possess none of the marked characteristics of the pure limes in slaking: they do not increase very

much in bulk, and the slaking takes a much longer time to accomplish.

Blue lias lime, from the rocks of the lias geological formation, is one of the best natural hydraulic limes. It is obtainable from Lyme Regis in Dorset, Keynsham in Somerset, Shipston and Rugby in Warwickshire, Barrow-on-Soar in Leicestershire, Aberthaw in Glamorganshire, also in Flintshire, Lincolnshire, and Yorkshire.

Hydraulic Lime Mortar.—Slake the lime the day previous by sprinkling it lightly with water, then turn it up together in a heap, and cover it with sand. The next morning it may be made into mortar by adding the proper proportions of sand and water.

One part of lime and 2 or $2\frac{1}{2}$ parts of sand make excellent mortar.

Gypsum—Chemical Analysis.—Plaster of Paris is anhydrous calcium sulphate, $CaSO_4$, and is produced by the gentle calcination in iron vessels of gypsum, which is a native hydrated sulphate of lime, occurring as a soft stone ($CaSO_4.2H_2O$) usually of a more or less crystalline texture, and varying in colour from white to shades of brown and grey to black. It is found in Derbyshire, Nottinghamshire, Cheshire, Westmoreland, and in great abundance near Paris. It contains in every 100 parts by weight 46·5 parts of SO_3, 32·8 parts of CaO, and 20·7 parts of H_2O. The raw stone is sometimes ground in the first instance and calcined in iron vessels. The very fine-grained pure white variety of gypsum is termed alabaster; the transparent, selenite.

Characteristics.—This is the only building material which at the time of setting expands in volume, this property making it valuable for filling up holes and other defects.

Uses.— It is used for making ornaments for ceilings, etc.,

and where plentiful may be used in all parts of a building where it is not exposed to the weather, for which it is unfit, being very soluble in water.

Its effect when mixed with the ordinary limes is to arrest the slaking and to increase the rapidity of setting.

Selenitic Cement or Selenitic Lime is an invention of General Scott, and is made by adding to the limes of the lias formation, which are the best for the purpose, or to the magnesian limestones or any lime possessing hydraulic properties, a small proportion of calcium sulphate in the form of plaster of Paris, mechanically mixed and ground with lime.

Chemical Synthesis. — The proportion of sulphate the cement usually contains is from 4 to 7 per cent., usual proportion being 5. When more than $7\frac{1}{2}$ per cent. of sulphate is required to suppress the slaking action, the lime is not suitable for selenitic cement, but may be rendered so by adding a lime that contains more clay.

Characteristics.—The sulphate suppresses the slaking action of lime, causing it to set more quickly, and enabling it to be used with a much larger ratio of sand than ordinary lime without loss of strength.

Uses.—For building mortar and plasterers' work.

Messrs. C. Nelson & Co., manufacturers of this material, issue the following instructions for the preparation of selenitic mortar for bricklayers' and plasterers' work:—

Patent Selenitic Blue Lias.—One bushel of lime (selenitic) requires about 6 gallons of water (about 2 full-sized pails).

If prepared in a mortar mill—

(1) Pour into the pan of the edge runner 4 full-sized pails of water.

(2) Gradually add to the water in the pan 2 bushels

of selenitic lime and grind to the consistency of creamy paste.

(3) Throw into the pan 10 bushels of clean sharp sand, burnt clay, or broken bricks, which must be ground till thoroughly incorporated (but overgrinding in the case of burnt ballast or broken bricks is apt to cause cracking). If necessary, water can be added to this in grinding, which is preferable to adding an excess of water to the prepared lime before adding the sand.

When a mortar mill cannot be used an ordinary plasterers' tub (containing about 30 or 40 gallons), or trough with outlet or sluice, may be substituted.

If prepared in a plasterers' tub—

(1) Pour into the tub 4 full-sized pails of water.

(2) Gradually add to the water in the tub 2 bushels of selenitic lime, which must be kept well stirred until thoroughly mixed with the water to the consistency of creamy paste.

(3) Form 10 bushels of clean sharp sand into a ring and pour in the selenitic lime from the tub through a $\frac{1}{4}$ mesh sieve (to avoid clods) adding water as necessary. This should be turned over two or three times, and well mixed with the larry or mortar hook.

Both the above mixtures are suitable for bricklayers' mortar or for first coat of plastering on brickwork.

Plastering on brick can be floated or straightened in one coat, and requires no hair.

For Plastering on Lathwork.—To the above quantity of water and selenitic lime add only 6 or 8 bushels of clean sharp sand and 2 hods of well-haired lime putty; the hair being previously well hooked into the lime putty. When the mill is used the haired putty should only be ground sufficiently to ensure mixing. Longer grinding breaks the hair, reducing it into shorter lengths, thus impairing its

bonding property. Lime putty should be run some time before it is used to avoid blisters.

This mixture will be found to answer equally well for ceilings as for partitions. If the sand is very sharp use only 6 bushels of sand for covering the lath, and when sufficiently set follow with 8 bushels of sand for floating (or straightening). When no mill is used it is sometimes preferred to make up a fat coarse stuff, with plenty of long hair, and to mix this with the selenitic lime and sand in the proportion of 1 part of coarse stuff to 3 parts of selenitic lime and sand, well larrying the whole together.

Setting Coat and Trowelled Stucco.—For common setting or finishing coat of plastering the ordinary practice of using chalk-lime putty and washed sand may be adopted. But if a very hard face is required selenitic lime, having been first passed through a 24 by 24 mesh sieve (to avoid the possibility of blistering), may be used in the following proportions: 3 parts lime putty, 2 parts washed sand, 1 part selenitic lime. This should be treated as trowelled stucco; first well hand-floating the surface and then well trowelling. A very hard surface is thus produced.

It is recommended that the workmen be supplied with suitable measures for the lime and sand to ensure that the proportions be adhered to. The want of this frequently leads to unsatisfactory results.

Selenitic lime must be kept perfectly dry until made into mortar for use.

It is of importance that the mode here indicated of preparing the mortar, etc., should be observed, viz.: well stirring the selenitic cement into the water before mixing it with the sand or other ingredient. This is the only point in which the preparation differs from that of ordinary mortar.

Selenitic lime should not be used in conjunction with gauged stuff for cornices, screeds, etc.

The sand or other ingredients should be always clean and free from loam.

No more selenitic mortar should be gauged than can be used in the same day.

Finely-ground burnt clay (ballast), or cinders, or stone chippings, as a substitute for sand, in whole or in part, can be used with great advantage in every description of work.

Selenitic plastering on walls can be finished in fine weather by the above processes, as 2 coat work in 24 hours, while the ceilings can be floated soon after the application of the first coat, and be set in 48 hours, but the time depends upon the state of the atmosphere.

Selenitic cement mortar, with 5 parts of sand, will be found to set harder and more quickly than common mortar with 2 or 3 parts.

Selenitic blue lias is very superior to that prepared from the ordinary grey lime, etc., for all purposes.

Puzzolana.—This is a volcanic substance found at Puzzola, near Naples, and in other parts of Italy, and consists of a compound of alumina and silica and traces of some of the metallic oxides, lime, potash and magnesia.

It is found, if mixed with preferably lias limes, to produce a hydraulic cement with a considerable compressional and adhesive value. This was used by Smeaton in the construction of the lighthouse built by him on the Eddystone rock. Puzzolana mortar is inferior to that made with manufactured Portland cement, and the expense of importation prohibits the use of puzzolana. An artificial puzzolana is made and largely used by grinding old well-burnt bricks and tiles, and adding to lime in lieu of sand to make mortar.

Trass is a similar material to puzzolana; it is obtained from Andernach in Germany.

Roman Cement is a natural cement prepared by burning at a low temperature nodules found in the London clay, and in the shale beds of the lias formation.

It contains about 40 per cent. of clay, is of a rich brown colour, and weighs, when ground, about 75 lbs. per bushel. It is kept in barrels, as on exposure to the atmosphere it absorbs CO_2 and moisture, and becomes inert. It should, therefore, be used fresh.

It is about one-third of the strength of Portland cement, and is much weakened by the addition of sand, which should never be used in a greater ratio than 1 to 1.

It sets very rapidly, usually in about fifteen minutes after mixing, and for this reason should only be mixed in small quantities as required. It is chiefly used for tidal and constructional work and where rapidity of setting is a necessity. It is now almost entirely supplanted by Portland cement for all works.

Medina is a similar cement to the Roman; it is lighter in colour, and answers the general description of the above. It attains a greater strength just after setting, but its final strength is not so great as Roman.

Harwich, Sheppey, Calderwood, Whitby, Mulgrave's, and Atkinson's are all natural cements, slightly differing in colour and characteristics, but very similar to the Roman.

Portland Cement.—A good Portland cement should contain approximately about 60 per cent. of lime, 20 per cent. of silica, and 5 to 10 per cent. of alumina, and small quantities of alkalies, oxides, etc.

On the Thames and in some parts of the Medway chalk and river mud are the raw materials used, and usually some

form of limestone rock is employed with the addition of clay. The usual process of manufacture is as follows:— Chalk and clay are combined in a wash mill, warm water being added to facilitate the combination, which is known as slurry. It is necessary at this stage to test if the mixture will make a good cement. This is done by taking a small quantity in a test-tube, and adding hydrochloric acid (HCl), then heating till the mixture is dissolved, and the inert matter is precipitated. On cooling a jelly is formed; if stiff, it is indicative that the mixture, with proper manipulation in the after processes, will turn out a good cement; if weak, it usually indicates that one of the ingredients must be augmented. This test also holds good if applied to hydraulic limes. When the slurry is properly formed, it is elevated and caused to flow by gravitation into settling tanks. The solid portion of the slurry is precipitated, the water is drawn off, the compound is then taken and placed on a drying-floor, where all moisture is driven off. From there it is taken and placed in the kiln, where it is burnt into clinker. On being withdrawn from the kiln it is sorted, the underburnt clinkers being put back in the kiln and reburnt. The remainder is crushed and passed successively through mills of various degrees of fineness; it is finally passed over a long rocking sieve, where the powder that passes through falls upon a revolving leather belt, which conveys it in a small stream into a cooling shed. The particles that do not pass through the sieve are reground.

Imperfect combinations of the raw materials or too much lime will produce a blowing cement; too much clay produces a contracting and quick-setting cement; overburning produces slow setting, and lightly burning produces quick setting.

The finer a cement is ground the less will be its weight per bushel, and at the same time it will be stronger,

consequently the weight per striked bushel and the fineness should be considered together in judging the quality of a cement.

Weight.—The cement should weigh from 110 to 115 lbs. per striked bushel; the fineness of grinding should be considered in relation to the weight; the finer a cement is ground the less is its weight, but at the same time if it is fine and heavy it will be stronger.

Colour.—Good cement is grey, or of a greenish-grey colour; a brown or earthy colour indicates too much clay, which would produce a quick-setting and contracting cement; a coarse bluish-grey cement would be over-limed and likely to blow.

Test for Coolness.—If the cement contains too much lime, or is underburnt, or not properly freed from unslaked particles, it has a tendency to crack and swell; this condition will be indicated by cracks and signs of expansion round the edges of the briquettes.

Practical Test.—Bricklayers plunge their hands in the sacks of cement; if hot, it has not been sufficiently exposed to the air; if at blood heat, it is fit for use.

Bottle Test.—Portland cement is also tested by mixing a quantity and filling a bottle while still wet. If the cement is too fresh, it will expand and crack the bottle; if it has been kept too long, it will shrink on setting and rattle in the bottle; if it is in a fit condition to be used, it will neither crack the bottle nor shrink on setting, nor rise out of it.

Storage.—Portland cement is received in bags or casks; it should be spread out to a moderate depth for a month or so on a wooden floor, and should be occasionally turned over, in order that the particles may become thoroughly air-slaked and cooled.

BRITISH STANDARD SPECIFICATION FOR PORTLAND CEMENT.*

1. *Quality and Preparation.*—The cement shall be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature and grinding the resulting clinker. No addition of any material shall be made after burning, except when desired by the manufacturer and if not prohibited in writing by the consumer, in which case calcium sulphate or water may be used. The cement, if watered, shall contain not more than 2 per cent. of water, whether that water has been added or has been naturally absorbed from the air. If calcium sulphate is used, not more than 2 per cent., calculated as anhydrous calcium sulphate, of the weight of the cement shall be added.

2. *Sampling and Preparation for Testing and Analysis.*—As soon as the cement has been bulked either at the manufacturer's works, or on the works in connection with which it is to be used, at the consumer's option, samples for testing shall be taken from each parcel.† Each sample shall consist of cement from at least twelve different positions in the same heap, so distributed as to ensure, as far as practicable, a fair average sample of the whole parcel, all to be mixed together and the sample for testing to be taken therefrom.

Before gauging the tests, the sample so obtained shall be spread out for a depth of 3 inches for 24 hours in a temperature of 58 to 64 degrees Fahr.

In all cases where consignments are of 100 tons and upwards, samples, selected as above from each consignment,

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† Should the consumer desire to stipulate for any special quantity, the size of the heap must be stated.

either at the manufacturer's works, or after delivery at the works where the cement is to be used, shall be sent for expert testing and for chemical analysis. In no case shall cement so tested and analysed be accepted, or used, unless previously certified in writing by the consumer to be of satisfactory quality. Payment for such tests and analyses shall be made by the consumer, the manufacturer supplying the cement required for the same, free of charge.

The tests and analyses hereinafter referred to shall in no case relate to a larger quantity of cement than 250 tons sampled at one time.

When consignments of less than 100 tons have to be supplied, the manufacturer shall, if required, give a certificate for each delivery, to the effect that such cement complies with the terms of this standard specification, with regard to quality, tests and chemical analyses, no payment being made by the consumer for such certificate, nor for the making of such tests and analyses.

3. *Sampling at Manufacturer's Works.*—Should it be deemed more convenient by the consumer that the samples for testing should be taken at the manufacturer's works before delivery, the latter shall, in that event, afford full facilities to the inspector appointed by the consumer to sample the cement as he may desire at the said works, and subsequently to identify each parcel, as it may be dispatched, with that sampled by him. No parcel shall be sent away unless a written order has been previously received by the manufacturer from the consumer, to the effect that the material in question has been approved.

4. *Fineness and Sieves.*—The cement shall be ground to comply with the following degrees of fineness, viz.:—

The residue on a sieve $76 \times 76 = 5{,}776$ meshes per square inch, shall not exceed 3 per cent.

The residue on a sieve 180 × 180 = 32,400 meshes per square inch, shall not exceed 22½ per cent.

The sieves shall be prepared from standard wire, and the size of the wire for the 5,776 mesh shall be ·0044 inch, and for the 32,400 mesh, ·002 inch. The wire shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

5. *Specific Gravity.*—The specific gravity of the cement shall be not less than 3·15, when sampled and hermetically sealed at the manufacturer's works, nor less than 3·10 if sampled after delivery to the consumer.

6. *Chemical Composition.*—The cement shall comply with the following conditions as to its chemical composition. There shall be no excess of lime, that is to say, the proportion of lime shall be not greater than is necessary to saturate the silica and alumina present.* The percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 3 per cent.; and that of sulphuric anhydride shall not exceed 2·5 per cent.

7. *Mode of Gauging.*—The quantity of water used in gauging shall be appropriate to the quality of the cement, and shall be so proportioned that when the cement is gauged it shall form a smooth, easily worked paste, that will leave the trowel cleanly in a compact mass. Fresh water shall be used for gauging, and the temperature thereof, and that of the test room at the time the said operations are performed, shall be from 58 to 64 degrees Fahr. The cement gauged as above, shall be filled, without mechanical ramming, into moulds of the form shown in Fig. A, Plate I., each mould resting upon an iron plate until

* The proportion of lime to silica and alumina shall be not greater than the ratio represented by $\frac{CaO}{SiO_2 + Al_2O_3} = 2{\cdot}75$.

the cement has set. When the cement has set sufficiently to enable the mould to be removed without injury to the briquette, such removal is to be effected. The said briquette shall be kept in a damp atmosphere for twenty-four hours after gauging, when it shall be placed in fresh water and allowed to remain there until required for breaking, the water in which the test briquettes are submerged being renewed every seven days, and the temperature thereof maintained between 58 and 64 degrees Fahr.

8. *Neat Test.*—Briquettes of neat cement of the shape shown in Fig A, Plate I., shall be gauged for breaking at seven and twenty-eight days respectively, six briquettes for each period. The average tensile strength of the six briquettes shall be taken as the accepted tensile strength for each period. For breaking, the briquette shall be held in strong metal jaws, of the shape shown in Fig. B, opposite, the briquettes being slightly greased where gripped by the jaws. The load must then be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in twelve seconds. The briquettes shall bear on the average not less than the following tensile stresses before breaking.

7 days from gauging ... 400 lbs. per square inch of section.
28 days from gauging ... 500 lbs. per square inch of section.

The increase from 7 to 28 days shall not be less than :—

25% when the 7 day test falls between 400 lbs. to 450 lbs. per square inch of section.
20% when the 7 day test falls between 450 lbs. to 500 lbs. per square inch of section.
15% when the 7 day test falls between 500 lbs. to 550 lbs. per square inch of section.
10% when the 7 day test is 550 lbs. per square inch or upwards.

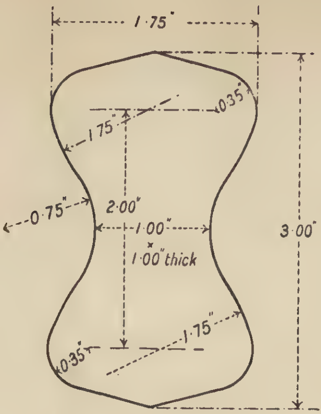


Fig. A

Dimensions of Briquette.

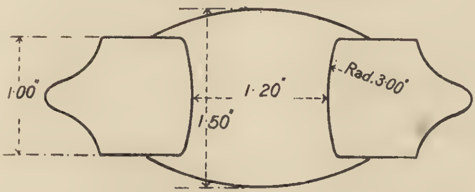


Fig. B.

Plan of jaw for holding Briquette.

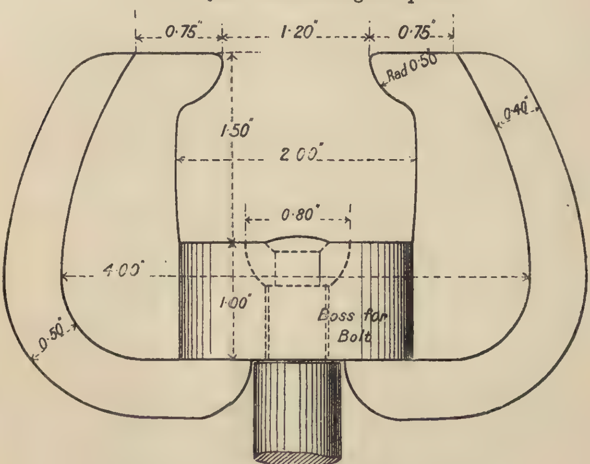


Fig. B.—Elevation of jaws for holding Briquette.

9. *Sand Test.*—The cement shall also be tested by means of briquettes prepared from one part of cement to three parts by weight of dry standard sand, the said briquettes being of the shape described for the neat cement tests; the mode of gauging, the filling of the moulds, and the breaking of the briquettes shall also be similar. The proportion of water used shall be such that the mixture is thoroughly wetted, and there shall be no superfluous water when the briquettes are formed. The cement and sand briquettes shall bear the following tensile stresses:—

7 days from gauging ... 120 lbs. per square inch of section.

28 days from gauging ... 225 lbs. per square inch of section.

The increase from 7 to 28 days shall not be less than 20 per cent.

The standard sand referred to above is to be obtained from Leighton Buzzard. It must be thoroughly washed, dried and passed through a sieve of 20 by 20 meshes per square inch, and must be retained on a sieve of 30 by 30 meshes per square inch, the wires of the sieves being ·0164 inch and ·0108 inch in diameter respectively.

10. *Setting Time.*—There shall be three distinct gradations of setting time which shall be designated as "Quick," "Medium," and "Slow."*

Quick.—The setting time shall be not less than ten minutes, nor more than thirty minutes.

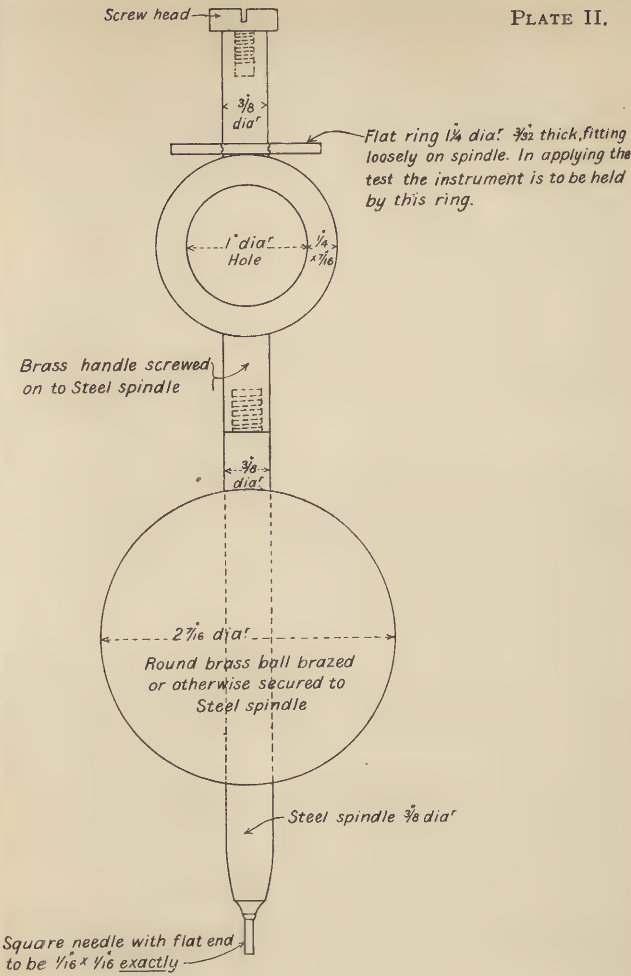
Medium.—The setting time shall be not less than half an hour, nor more than two hours.

Slow.—The setting time shall be not less than two hours, nor more than five hours.

The temperature of the air in the test room at the time of

* When a specially slow setting cement is required the minimum time of setting shall be specified.

PLATE II.



Note. 1. The total weight of the Instrument, exclusive of the flat lifting ring, must be exactly 2½ lbs.

2. The end of the needle must be exactly 1/16 square

Fig. C.—Sketch of "Needle" for ascertaining setting time of Cement.

gauging, and of the water used, shall be between 58 and 64 degrees Fahr.

The cement shall be considered as "set" when a "needle" of the form shown in Fig. C, Plate II., having a flat end $\frac{1}{16}$-inch square, weighing in all $2\frac{1}{2}$ lbs., fails to make an impression when its point is applied gently to the surface.

11. *Soundness.*—The cement shall be tested by the Le Chatelier method and shall in no case show a greater expansion than 12 millimetres after 24 hours' aeration and 6 millimetres after seven days' aeration.

The apparatus for conducting the Le Chatelier test (Fig. D, Plate III.) consists of a small split cylinder of spring brass or other suitable metal of 0·5 millimetre (·0197 inch) in thickness, forming a mould 30 millimetres ($1\frac{3}{16}$ inches) internal diameter and 30 millimetres high. On either side of the split are attached two indicators with pointed ends, A A, the distance from these ends to the centre of the cylinder being 165 millimetres ($6\frac{1}{2}$ inches).

In conducting the test, the mould is to be placed upon a small piece of glass and filled with cement gauged in the usual way, care being taken to keep the edges of the mould gently together while this operation is being performed. The mould is then to be covered with another glass plate, a small weight is to be placed on this and the mould is then to be immediately placed in water at a temperature of 58 to 64 degrees Fahr., and left there for 24 hours.

The distance separating the indicator points is then to be measured, and the mould placed in cold water, which is to be brought to boiling-point in 15 to 30 minutes and kept boiling for six hours. After cooling, the distance between the points is again to be measured; the difference between the two measurements represents the expansion of the cement, which must not exceed the limits laid down in this specification.

PLATE III.

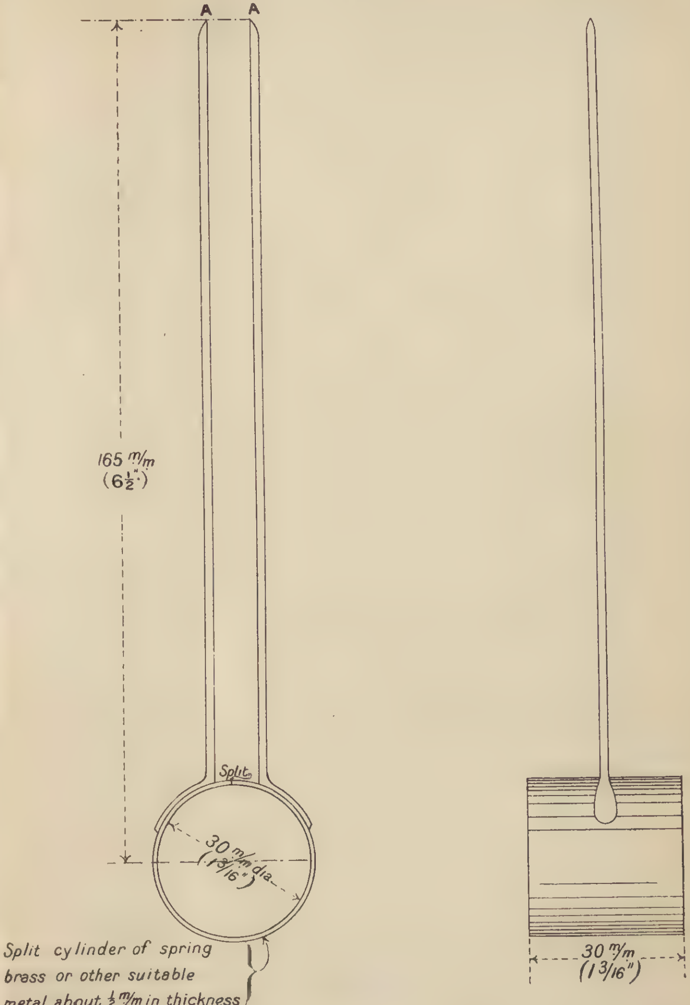


Fig. D.—Sketch of Apparatus for conducting the "Le Chatelier" Test.

12. *Acceptance.*—No cement shall be approved or accepted unless it fully complies with the foregoing conditions.

CONCRETE.

Concrete is an artificial stone made by mixing lime or cement with small pieces of stone, brick, or other hard substances, and water in such a ratio as to allow of the stones becoming embedded and entirely surrounded by the cementing material, the whole forming on setting a perfectly homogeneous mass.

Uses.—Concrete is used in foundations, walls, floors, staircases, and roofs, for which it is eminently suitable. The composition varies according to the purpose for which the concrete is to be used: heavy concretes with a high crushing resistance are employed for foundations, retaining walls, and engineering works generally, whilst the lighter mixtures are preferable for floors, staircases, and roofs.

Constituents.—Concrete is composed of two parts—first, the matrix; secondly, the aggregate.

The matrix is the cementing material, which may be either lime or cement. If lime be used, it should be of the kind known as hydraulic, finely ground. Blue lias is the best hydraulic lime produced in this country for concrete. Roman cement is sometimes used for tidal works on account of its quick-setting properties. It should be used fresh, or the concrete made from it will be of an inferior quality.

Owing to the great improvement made in the manufacture of Portland cement in recent years, limes and the natural cements have been almost superseded for concrete works, the superior setting qualities, together with the greater uniformity in resistance where large quantities are used, and its great strength renders Portland cement much more reliable as a matrix.

Aggregate.—The aggregate may be of any of the following materials:—Broken stone, broken brick, ballast, burnt clay, coke breeze, or any other hard or imperishable substances. The pieces should be no larger than will pass through a $1\frac{1}{2}$ inch to 2 inch mesh, clean and free from all argillaceous or earthy matters.

Broken stones or bricks are considered to be better than ballast for aggregates because the former are more angular and the surfaces are rougher, and therefore in a better condition to adhere to the matrix; the pieces also fit more closely together, and do not require such a large proportion of the matrix.

The aggregate should be wetted before mixing with the matrix, otherwise it will absorb the moisture from the matrix and thereby destroy the cohesion of the mass.

Mixing.—Great care should be taken in the mixing of concrete to keep the mass free from all earthy matters. To accomplish this, the compound should be mixed on a wooden platform at least 10 feet square, slightly raised above the ground level. The aggregate is then shovelled on the platform into a measure, which consists of a box with four sides only.

A small and similar box (the cubic content of which bears the same ratio to the content of the large measure as the matrix bears to the aggregate in the concrete to be mixed) is placed on the aggregate before the large measure is removed. The matrix is then measured, and the two boxes, which are bottomless, are removed, leaving the constituents in a conical shaped mound on the platform; the compound is then turned over twice in a dry condition, and lastly, for a third time, water being added by means of a can with a rose head. The mass, being then thoroughly mixed and hydrated, is shovelled into barrows or pails, transported to the place required, and gently tipped into

position, and consolidated by being beaten with shovels or beaters.

Reduction in Bulk.—The dry materials of which concrete is composed, when mixed with water and shot into position and beaten, become reduced in bulk, owing to the pieces of the aggregate getting packed closer, the average amount of the shrinkage being about ·33 of the total bulk. This important point should be noted in estimating the quantities for concrete work.

Selection of Aggregate.—The aggregates for concretes vary for the parts of the building for which they are intended, as they are required to satisfy different conditions.

Foundations.—The object of concrete in foundations is to distribute the superincumbent weight over a greater area of ground than would be the case if the wall were built directly upon the subsoil. The primary stress, therefore, that it has to resist is compression, and for this no better material than ballast, which is practically incompressible, could be found. But if the ground be uneven or variable in its strength, the concrete may be called upon to act as a beam, as it would rest upon the hard places and tend to settle under the weight over the softer parts. A certain amount of tensile strength is in this case needed, and a material which has a higher adhesive value than ballast, such as broken stone or broken brick, should be employed.

Walls.—Walls are subject to compressive and to bending stresses; in many cases the bending stress being greatly increased by the wind. Walls depend upon their mass and the cohesive strength of their parts for their stability; therefore the concrete for walls requires a larger amount of matrix than is requisite for foundations, and it is necessary for the aggregate to be of some material capable of bonding

or interlocking, such as broken bricks or broken stones. Walls are also subject to injury by fire; therefore the material must be capable of being heated and suddenly cooled without having the tendency to fly to pieces, or deteriorating to such an extent as to render it dangerous. Portland cement is the best matrix to comply with the above condition, and broken fire or other sound bricks are the best aggregates.

Floors.—Concrete for floors should be light, strong, and fire-resisting, as floors are subject to cross stress, due partly to the loads applied, and to their own weight, and are also called upon to resist the action of fire.

Portland cement is the best matrix, but plaster of Paris or gypsum has been largely used for this purpose; the latter forms a fairly strong concrete under ordinary conditions, but is liable to failure when suddenly cooled after heating.

The aggregates mostly used for floors are broken firebrick, coke breeze, ash breeze, and pumice-stone. Firebrick is chosen for its refractory qualities, and broken hard stocks are also largely used for fire-resisting purposes; ash breeze and pumice-stones are also good aggregates, as they are eminently fire-resisting, and they are also very light. Coke breeze is very light, but is unsatisfactory to resist fire compared to the other aggregates previously mentioned.

Stairs.—These have to satisfy the same conditions as floors, and in addition have often to be fixed as cantilevers, and must be tough and hard to resist wear. To resist the tensional stresses the concrete is used with iron; to resist wear, aggregates of a hard nature, such as granite chippings, are employed.

Roofs.—The concrete for roofs and domes, not being required to support any external loads, but only for fire-resisting purposes, should be formed of the lighter aggregates, pumice or coke breeze, the latter being considered the better, as it affords opportunities for fixing the covering.

The undermentioned table is a result of experiments made by Mr. Webster, and given in the "Minutes of Proceedings of the Institution of Civil Engineers" (1890–1891), and may be useful in selecting the best fire-resisting concretes:—

	Nature and Proportions of Materials in Concrete Briquettes.	Average Weight per Cubic Foot.	Tensile Breaking Weight per square inch at Temperature of 60° Fahr.	Tensile Breaking Weight per square inch after being Heated & Quenched.
		lbs.	lbs.	lbs.
1	Neat Portland Cement ...	124·6	554·6	117·2
2	1 part Cement, 1 part Sand ...	120·9	448·0	93·0
3	1 ,, ,, 3 ,, ,, ...	111·2	100·8	18·7
4	1 ,, ,, 5 ,, ,, ...	109·7	74·6	15·0
5	1 ,, ,, 4 ,, iron furnace slag	163·08	108·1	23·06
6	1 ,, ,, 4 ,, broken fire-brick	95·04	84·4	30·5
7	1 ,, ,, 4 ,, pumice-stone	64·8	94·58	38·3
8	1 ,, ,, 4 ,, coke breeze	71·65	69·9	39·06
9	1 ,, Plaster of Paris, 4 parts broken fire-brick ...	89·6	66·8	10·3
10	1 ,, Plaster of Paris, 4 parts pumice-stone ...	55·6	57·4	3·4
11	1 ,, Plaster of Paris, 2 parts furnace slag ...	148·0	223·3	6·9
12	1 ,, Plaster of Paris, 2 parts broken fire-brick ...	106·9	167·5	15·7

Compressional Strengths of Concrete.—The following tables will be found useful in determining the values for the compression of concrete. The first is a record of experiments made by Mr. Baker, Watertown Arsenal, U.S.A. 12″ cubes of broken stone concrete in which the voids were practically filled with mortar tested 600 days after moulding and kept in water during the interval :—

Composition.		No. of cubes tested.	Average crushing strength in lbs. per square inch.	
Cement.	Sand.			
1	1	3	4467	Individual tests agreed well.
1	2	6	3731	
1	3	6	2553	
1	4	6	2015	
1	5	2	1796	
1	6	1	1365	

Professor Hatt, of the Purdue University, U.S.A., in 1902 gave the results of the following tests :—

Proportions of the Concrete.			Age.	E_c	Stress where measured in lbs. per square inch.	Crushing stress in lbs. per square inch.
Cement.	Sand.	Stone.				
1	2	4	9 days	$1\cdot66 \times 10^6$	1000	1944
1	2	4	3 months	$3\cdot46 \times 10^6$	1000	2200
1	2	4	6 months	$4\cdot50 \times 10^6$	1000	3500
1	3	6	9 days	$1\cdot95 \times 10^6$	1000	2308
1	3	6	3 months	$3\cdot75 \times 10^6$	1000	2500
1	3	6	6 months	$2\cdot81 \times 10^6$	1000	3500

In a later paper Professor Hatt gives the following :—

Proportions of the Concrete.					Age in Days.	Elasticity of the Concrete in Compression.	Stress where measured in lbs. per square inch.	Crushing Stress in lbs. per square inch.
Cement.	Sand	Broken Stone.	Gravel.	Cinders.				
1	2	4	—	—	9	$4·70 \times 10^6$	750	2880
1	2	4	—	—	9	$3·94 \times 10^6$	1500	
1	2	4	—	—	14	$4·34 \times 10^6$	750	2575
1	2	4	—	—	14	$3·68 \times 10^6$	1500	
1	2	—	—	4	9	$5·58 \times 10^5$	—	495
1	2	—	—	4	9	$5·53 \times 10^5$	—	595
1	2	—	—	4	7	$6·30 \times 10^5$	—	416
1	—	—	5	—	6	$2·09 \times 10^6$	—	1185

Transverse Strengths of Concrete Beams.—The following table gives the calculated values of C based upon the experiments of the stated authorities :—

Portland Cement.	Sand.	Aggregate.	Age in Days.	Breadth.	Depth.	Clear Span.	No. of Tests.	Loaded at.	Average Breaking Weight.	Reduced Breaking Weight at Centre.	One-half Weight of Beam between Supports.	Total Central Load.	Constant per square inch (Calculated Value of C in cwts.).	Authority.
				Ins.	Ins.	Ins.			Cwt.	Cwt.	Cwt.	Cwt.		
1	0	4 clean breeze	43	30	6·5	59	1	Central, 16″	66·32	57·32	2·12	59·44	4·15	C
1	0	4 broken brick	43	30	6·0	59·5	1	Central, 16″	40·52	35·07	2·53	37·6	3·11	C
1	0	5 shingle	139	12	12	36	1	Centre.	85·52	85·62	1·77	87·39	2·73	D
1	2	2 broken stone, 1½″ 4 broken stone, 3½″	90	12	12	36	3	Central, 6″	52·5	48·12	1·76	49·88	1·56	B
1	2	6 broken stone, 1½″	90	12	12	36	3	Central, 6″	40·83	37 43	1·76	39·19	1·22	B
1	0	9 shingle	95	12	12	18 36	1 1	Centre	3·06 8·33	83·06 38 33	0·77 1·53	83·83 39·86	1·31 1·24	D

Authorities :—C, Col. Crozie ; D Darnton Hutton ; B, John Kyle.

Transverse Strengths of Concrete Beams based upon Seddon's Experiments.—Sutcliffe applies the following formulæ to the results obtained by Col. Seddon on slabs supported all round and uniformly loaded with layers of bricks. In calculating the value of C it is assumed that the strength of slab No. 4, which is nearly square, is 20 per cent. less than if the edges had been fixed, and that of the remaining slabs 25 per cent. less.

Sutcliffe suggests that the strength of a square plate fixed at the edges and uniformly loaded may be calculated from the following formula based upon Grashof, where

w = breaking weight in cwts. per square foot
L = length of each side in feet
t = thickness in inches
W = total load on slab.

$$W = 4C\frac{t^2}{L^2}$$

but as total load on square slab uniformly loaded $= w \times L^2 = W$

$$w\,L^2 = 4C\frac{t^2}{L^2} \times L^2$$
$$W = 4C\,t^2$$

The formula for supported square plates uniformly loaded may be taken to be ·8 of the strength of the square slabs uniformly loaded, fixed at edges; therefore this will be

$$w = 3{\cdot}2\,C\frac{t^2}{L^2}$$

The strength of rectangular plates fixed at the edges and uniformly loaded may be calculated from the following formula, where B = breadth of slab in feet.

$$w = 2C\,\frac{L^4 + B^4}{L^4} \times \frac{t^2}{B^2}$$

Composition.				Length between Supports.	Breadth between Supports.	Thickness	Age in Days.	Breaking Weight per square foot.	Weight of Slab per square foot.	Total Breaking Weight per square foot.	Calculated Value of C.
Number.	Portland Cement.	Sand.	1 inch Crushed Brick.								
				Ft.	Ft.	Ins.		Cwt.	Cwt.	Cwt.	
1	1	0	4	14·5	6·75	6	7	3	·54	3·54	2·85
2	1	0	4	,,	,,	,,	14	2·76	,,	3·30	2·66
3	1	0	4	,,	,,	,,	21	8·88	,,	9·42	7·58
4	1	0	4	,,	13·5	,,	,,	1·07	,,	1·61	2·90
5	1	·75	3	,,	6·75	,,	14	2·51	,,	3·05	2·45
6	1	·75	3	,,	,,	,,	21	2·84	,,	3·38	2·72

An example illustrating the use of the above is given in the Chapter on Foundations.

Specifications for Concrete.

(*a*) War Office.—The concrete to be made in the proportion of 1 part Portland cement and 6 of clean Thames ballast or other approved material broken to 1½-inch gauge, and 1 part sand as may be found in the ballast. An interval of seven days, or as may be directed, is to elapse between the completion of the concrete foundations and the commencement of the building of the walls upon them.

(*b*) London County Council.—The concrete for foundations must be composed of clean gravel, broken hard brick, properly burned ballast, or other hard material to be approved by the district surveyor, well mixed with freshly burned lime or cement, proportions of 1 of lime to 6 and 1 of cement to 8 of the other material.

(*c*) L.C.C., Walls.—The concrete for walls to be composed of Portland cement and clean Thames or pit ballast or gravel, or broken brick or stone or furnace clinkers, with clean sand

in the following proportions :—1 part of Portland cement, 2 parts of clean sand, and 3 parts of the coarse material which is to be broken up sufficiently small to pass through a 2-inch ring.

ASPHALTE.

Definition.—Combinations of bituminous and calcareous compounds are termed asphaltes, and these may be divided into (*a*) natural, (*b*) artificial. The natural are the asphaltes that are important for use in building works (probably because the bitumen is more thoroughly mixed with the calcareous substances), and consist of asphalte rock taken and pulverized by any method, and thrown in small quantities at a time into melted bitumen equal to 7 or 8 per cent. of the weight of the powder employed, and the mixture boiled for five or six hours, continuously stirring it by means of revolving agitators; a paste will be the resultant, which, when run into moulds, produces what is known as bituminous mastic or cement.

Chemical Composition.—Natural asphalte is a bituminous limestone of a rich brown colour, found in large quantities in France and Switzerland, the component parts of which in its rock condition consist of nearly pure calcium carbonate impregnated with about 10 per cent. of mineral tar; this latter is also known as bitumen. The latter is found sometimes in the free state, sometimes mixed with clay, and at other times cementing together sand and stones. The analyses of bitumen give the following composition by weight:—Carbon, 87; hydrogen, 11·2; and oxygen, 1·8 per cent. respectively (Boussingault), and is a substance of a beautiful black colour, reflecting a reddish light, solid at low temperature, ductile at the temperature of the hand, liquid at about 50° to 100° Centigrade, and is very stable, since it loses scarcely 1 per cent. of its weight when heated to 250° Centigrade.

Coal tar pitch is the residue left on distilling coal tar. It is sometimes used, instead of true or mineral bitumen, for mixing with asphalte. It is, however, brittle, softens more readily under heat, is easily crushed, is altogether inferior, and therefore should not be used.

Characteristics.—The distinguishing properties of asphalte are as follows:—Sanitary, damp resisting, tough, durable, noiseless, non-absorbent, quickly drying after rain, non-inflammable, proof against frost, safe against vermin, can be cleansed easily, slightly elastic (which is good for floors and roofs, as it yields a small amount without cracking), and it is relatively economical. It is not in any way deteriorated by urine, and is laid without joints and seams, and when used for covering ground prevents water from percolating from above or below.

Varieties and Use.—The two varieties in use are (*a*) powdered, (*b*) mastic. The first is the natural rock ground to a powder, and when required for use is subjected to a great heat, and compressed by being rammed when *in situ*.

In the second case, the bituminous limestone is reduced to a fine powder, with which is mixed a certain proportion of grit of uniform size and free from dust. In this state it is by degrees put into large stationary cauldrons, heated by fires, in which sufficient mineral tar to prevent the asphalte calcining has been melted. By means of powerful machinery these are kept constantly agitated for several hours till the whole mass has become thoroughly amalgamated and reduced to a mastic; it is then run into moulds forming blocks, weighing about 125 lbs. This mastic is made in three qualities — the fine, fine gritted, and coarse gritted. The fine, not having any admixture of grit, is employed for magazine floors, and in special cases as a cement for making very close joints in brickwork.

The fine gritted is used as a covering for roofs, arches, linings of tanks, as a cement for brickwork, and for running the joints of stones. The coarse gritted, containing a larger grit and greater quantity than the former, is used for flooring and paving, and where great strength of work is needed, such as gun-shed floors, tun-room floors, margin of stable floors, and in gateways for heavy carriage traffic. These mastics, and more especially the first two, are ductile, and readily yield without cracking to any change likely to take place on the surfaces upon which they are laid; this makes them specially suitable for foundations, floors, and roofs.

The mastic blocks are brought to the works, they are then broken up, melted in cauldrons, spread on the site, screeded to required thickness, and rubbed and finished with hand floats to a smooth surface. This is good for foundations, floors, roof coverings, and building work generally.

Plates are often cast horizontally, and then placed in a vertical position and jointed to form skirtings.

Precautions.—The principal points to be attended to in all works in asphalte are the following:—The foundations must be solid, the concrete or brickwork must be dry before the application, the asphalte must be very hot, and the joints made to perfectly adhere to one another. To prevent any failure of the joints in exposed positions (such as would occur in roofs and vaults, where it is all important to have perfect joints), that part of the concrete parallel to the joint should be scraped out to the extent of three inches, and to a depth of three-eighths of an inch, and filled in with a layer of asphalte. Upon, and in the centre of this layer, the joints of the upper coat should be made to meet.

Repairs.—When any part of the asphalte needs renewal, it may be remelted and relaid.

The best mode of effecting this is to pour over that

part of the old work requiring removal, some hot asphalte, which latter needs to remain a short time and then be removed.

By this means it is softened, and may, without danger of fracture to the other parts, be readily cut up with a stiff knife.

In every case great care must be taken to make good the foundation and cleanse the edges of the asphalte remaining, which should, when heated, as before explained, be cut square to a straight edge that the repairs may be neatly executed.

Noted Asphaltes.—The following are considered as the best asphaltes in the market:—The Seyssel (known as Claridge's Patent Asphalte), obtained from the Jura Mountains, in France, and largely specified for building works; and the Val de Travers, obtained from the mines at Neuchatel, Switzerland, immense quantities of which are used in constructing roadways.

Artificial Asphaltes.—Artificial or British asphaltes are formed of an admixture of pitch, chalk, sand or sawdust, and ground iron slag, heated and laid in a semi-fluid state. These are, as already stated, considerably inferior to the natural asphaltes.

Hygeian Rock Composition is a bituminous cement, the constituents of which are not made known by the patentee, W. White, of Abergavenny, Monmouthshire. It is laid similarly to asphalte, and is considered effective and economical for horizontal or vertical damp-proof courses. It is claimed, when used vertically in the body of a brick wall, to impart a strength equal to a wall of double its thickness.

Its characteristic properties are that it is damp proof, and to a great degree non-conducting and vermin proof, it has considerable adhesive strength to brickwork, and is

especially applicable for making damp-proof water tanks or cellar walls, and is laid for about half the cost of Seyssel asphalte.

PLASTERING.

Definition.—Surfaces covered by any calcareous compound are said to be plastered. External work is usually completed in two coats, whilst internal plastering is more often effected in three layers. The first coat placed against a brick or stone wall is called rendering; when applied over wood laths or wire netting it is termed pricking up: the second or intermediate is called the floating coat, and the third or finishing, the setting coat, and generally any calcareous covering, whether put on in one, two, or three coats, is known as plastering.

Classification.—The work of the plasterer may be divided under two heads, viz., external and internal work.

External Work.—Outside plastering is employed as a protection to walls from the weather, and to present an appearance similar to stonework. Of late years it has fallen into disuse owing to the great improvement in the manufacture of bricks, terra cotta, and other polychromatic material, and the increased facilities for obtaining these, also stones from the numerous quarries since the introduction of railways, and added to which, the knowledge that plastering has been extensively used to cover and improve the appearance of inferior and bad brickwork is causing an amount of discretion to be displayed before resorting to it as an external covering; but it is still used extensively about the coast, where it is found to efficiently and economically resist the action of the weather, if properly executed with Portland cement and clean sharp sand.

Cements.—Portland and Roman are the two cements most generally used for external work. Of these, Portland is the more durable, and is better for plain work; but for

moulded work Roman is often preferred, as it works fatter, and much finer arrises are to be obtained with it than with Portland, but it is not nearly as durable. Roman cement also has the advantage that it may be painted shortly after it has been laid on, while Portland has to remain until thoroughly dry, which takes several months to accomplish, and it is due to this that Roman cement is often used for repairing work.

Method of Rendering.—Large surfaces, such as the fronts of houses, are rendered as follows:—The joints of the brickwork are raked out for a depth at least $\frac{3}{4}$ inch, and the surface is hacked in order to form a key for the first coat of stuff, or a good method is to have the work built in good rough stocks with uncut and protruding joints; illustrations of these face joints are given in the chapter on brickwork in my Elementary Course. This applies also to interior work. The whole front is then well brushed with a hard broom, in order to remove any dust, and well wetted to assist the adhesion of the mortar. A wooden rule or straight edge is then generally nailed upright at each end of the building, the front edge of each rule being kept $\frac{1}{2}$ inch or $\frac{3}{4}$ inch in front of the wall as a guide for the thickness of the first coat of plastering.

It is a good plan to run next, horizontal screeds through the entire length of the building, to serve as guides for the vertical screeds, which are next formed at intervals varying from 4 to 10 feet along the building. All these screeds are brought into the same vertical plane with the front edges of the two fixed rules, this being accomplished by first making the horizontal screeds straight and flush with the rule edges, the straightness being tested by stretching a line from rule to rule.

These screeds are narrow bands of the material with which the wall is to be plastered. They are brought to

a face and straightened by means of a floating rule, and really form portions of the face of the first coat of plaster. Instead of running horizontal screeds to use as guides for vertical screeds, it is very common to use nails, one being driven into the wall wherever it is intended that a vertical screed shall terminate, a line is stretched along the face from rule to rule to indicate how far each nail should be driven in.

When the screeds are sufficiently hardened, the spaces between are rendered over and brought to the required face by means of a floating rule, which works either on one of the straight edges and the adjacent screeds, or else on two adjacent screeds.

The face of the rendering coat should be left rough in order to afford a good key for the fining. With suitable sand this may be effected in the ordinary course of ruling off, but if the sand works too smoothly, as is often the case, the face should either be scraped over with a ragged edge rule when the water has gone off, or else it should be swept over with a stiff broom; either of these is far preferable to the method of scratching the face.

The work should not be allowed to stand many days before the finishing coat, or, as it is usually termed, the fining, is laid on, as the two will hold together very much better if the first coat be not thoroughly set when the other is laid over it.

The fining is usually about $\frac{1}{8}$ inch in thickness. Inferior work is laid on with some approximation to uniformity with the hand-float, and then finished off with it. In work of a better description, it is brought to a uniform face with a short traversing rule, and then finished with the hand-float, which is best made of pine. In finishing, the surface is wetted with a brush and worked up with a wood hand-float with a circular motion; the whole surface is well worked in this manner; this process is termed scouring. Its effect is to harden and consolidate the surfaces.

In order to avoid the smeared appearance sometimes presented by fining, it should be hand-floated until the gloss has gone off the face. The work is generally jointed afterwards, to imitate ashlar blocks (but this being a sham is a treatment to be avoided); this is done by forming lines on the face slightly more than $\frac{1}{8}$ inch wide and of same depth. This jointing is best done by using a jointer, with which the joint is ironed in; in this way cleaner joints are formed, which are at the same time more impervious to the wet. In order to apply this method the jointing must be done before the fining is set.

The rendering coat is usually of 1 of Portland cement to 3 or 4 of sand, and for the fining coat 1 of Portland cement to 2 of sand. The matrix must be, for good work, of the same material for both coats.

Projections.—The reveals, sills, string-courses, plinths, and mouldings of a brick-faced building are sometimes executed in Portland cement, and this when properly carried out, is found to resist the weather as well as stone dressings; in fact, better than some of the soft stone now largely used. It is less liable to decay through the action of the weather; and if injured by frost, it is generally because wet has by some means got *behind* it rather than *through* it.

Wherever any projections are to be formed, they must be first backed out in brick or stone to within an inch of the finished surface.

Throated sills or copings are formed in cement by a sill box, encasing the brick backing, temporarily supported on brackets or otherwise in the required position, provision having been made to bond the tiles or bricks forming the backing well into the wall so as to get a good tie. It is then coated with cement, and when sufficiently set the supports are removed and the box gently tapped until loose enough to be detached.

The bottom and sides of the box are generally oiled or soft soaped to prevent the cement adhering to the mould.

The tops of all sills and copings should be well weathered to throw off the water, and also throated on the under edge to prevent the water running down the wall.

Sills and steps are often moulded before fixing.

Casting of Sills, Copings, Ornaments, etc.—When casting ornaments for external use it is well to use Portland cement. One of the chief difficulties to surmount in the casting with slow-setting Portland cement, is the tendency of the water to gradually trickle away if there is any escape for it; this will honeycomb the face of the casting, and to remedy which will take considerable time. Moulds are made either as (1) waste moulds for one casting or (2) piece moulds for two or more castings.

The moulds are usually of wood, gelatine, or plaster.

Wood moulds are used for plain work such as sills or simple mouldings.

Gelatine moulds are used for undercut work only.

Plaster moulds are used in most cases, the process being as follows:—The subject is first modelled in clay; then for the waste mould a slip of plaster of Paris—that is the latter mixed with water to a semi-fluid condition—and generally some pigment is added if the final casting is to be in plaster of Paris, in order that when the mould is broken away it may be easily distinguished from the casting. The slip is poured over the model, taking care that it enters all the quirks and hollows without leaving any air bubbles, and immediately the slip is backed up with plaster of Paris, mixed somewhat stiffer than the latter, until a good body of material is formed capable of holding together without any support when set. When the material has set the clay model is withdrawn from the mould, being destroyed in the operation. The mould is cleaned, and if any parts are defective made good,

after which it is soft soaped to prevent the final casting adhering. The cement or plaster of which the casting is to be formed is mixed up in slip condition and applied in the mould, being immediately backed up with similar material mixed to a stiffer condition, to usually about 1 to $1\frac{1}{2}$ inches in thickness. If the casting is in cement and to be used for constructional purposes, it is then filled in solid with fine concrete; if in plaster and the casting is large, it is usually backed with coarse canvas, through the meshes of which the plaster can easily permeate, and with thin strips of wood or stout iron wire to give stiffness to the work. When the casting is set the mould is carefully broken away. If several castings are required to the same pattern, the mould is made in several pieces, in such a manner that the pieces may fit into all the undercut portions and yet still be possible to withdraw them without destroying or injuring the castings that are made from them. Considerable ingenuity and experience is necessary before difficult designs can be executed successfully by this method. When the pieces are altogether, they are enclosed by a plaster box made to receive them. The casting operation is executed as before described, the mould being carefully examined and repaired if required after each casting.

If a number of Portland cement castings are required to be formed with the same mould expeditiously the pressing method is adopted, as it is not necessary by this arrangement to wait until the casting has set before removing the mould.

The pressing method is as follows:—The stuff is rammed into the mould by hand in a condition just damp enough to hang well together; the mould may be taken to pieces and away from the casting, the latter being turned carefully on to a board; it should be left until sufficiently set when it should be well soaked in water and left to harden. Very good work may thus be obtained by using equal quantities of Portland cement and sand.

Steps.—Flights of steps are frequently formed in Portland cement and concrete. Wood moulds for the construction of a complete flight are erected, having soffit boards, string boards and risers. If the steps have moulded nosings and the strings are moulded, the reverse of the mouldings must be worked on the strings or riser boards; if the soffit is panelled and moulded, projections must be fixed to the soffit boards to form them. Neat Portland cement, or Portland cement and clean-washed sand, 1 to 1, are well mixed and plastered over the soffit, string and riser boards, and are immediately filled in with fine concrete so that the face and backing shall properly unite. The treads are floated in last; about three steps at a time are formed. By the time the third tread has been floated the mass will have become sufficiently rigid to allow of the next series being proceeded with.

Internal Work.—The following are the cements chiefly used for internal work, viz., Portland, Parian, Keene's, Martin's, chalk lime, sirapite and selenitic lime.

Mouldings.—For running mouldings it is customary to fix two rules, one for the slipper of the horse, and the other for the nib to run against. The material is laid on gradually, unless it sets very quickly; the mould is repeatedly run along the rules until the moulding is brought into shape, and it is then finished either with hand-floats of different shapes and sizes, or with the joint rule. In running mouldings in Portland cement there is a great temptation for plasterers to kill the stuff—that is to allow the plaster to partially set, and then to mix it together again, as it works much fatter and so saves much labour if knocked up again when partially set. This should never be allowed, as it is very detrimental to the cement.

Floors.—Layers of Portland cement and sand are used as a covering to concrete floors in order to form a finished

surface, and are applied in one or two coats. One-coat work is laid $\frac{1}{2}$ inch to 1 inch in thickness. In two-coat work, the first coat is generally from $\frac{3}{4}$ inch to 1 inch in thickness, and is prepared with coarse sand containing a large proportion of fine shingle. The first coat consists of 1 of Portland cement to 4 of sand and shingle, the fine or floating coat of 1 of Portland cement to 1 of sand. Where floors are finished in this way, if possible, the first coat should be applied before the concrete is quite set. In two-coat work the floating coat should always be applied before the first coat has set.

In each case the work is brought to the required form with a floating rule, and is then hand-floated and finished with the trowel.

Walls. — Internal surfaces of brick walls are treated similarly to the surfaces of external walls, already described, and are rendered with a first coat of Portland cement mortar, consisting of 1 part Portland to 2 parts of washed sand, if the walls are likely to be damp, but for internal walls that will be permanently dry the ordinary plasterer's coarse stuff is used.

Internal brick or timber stud walls are usually covered with three coats, the object of the first rendering or pricking-up coat is to get a key for the second or floating coat, the former being brought to an approximately plane surface by means of floats worked on horizontal or vertical screeds, those latter being formed of the coating material, about 2 inches wide and situated about 8 feet apart, having been made plumb and linable with each other, and which have been allowed to set. The straight edge used is known as a Derby float, and is about 10 feet long, 7 inches wide, and $1\frac{1}{2}$ inches thick. The surface of the pricking-up coat before hardening is scratched with a few pointed laths, or a coarse hard broom is drawn in various directions over the work in

order to form a key for the floating coat, the latter being lightly scratched to receive the finishing or setting coat, which is put on with a hand-float or trowel, and brought to a fine surface.

Lathing.—Laths are thin strips of oak or fir varying from 2 feet to 3 feet 6 inches long and 1 inch wide, nailed on the underside of joists or over the surface of quarter partitions to form a ground for the pricking-up coat.

The laths are fixed about $\frac{3}{8}$ inch apart, so that the coarse stuff when trowelled on may be squeezed through the interstices and protrude on the back side of the laths, overlapping the edges, thus forming a key for the pricking-up coat.

The laths are fixed with iron nails with clout heads; these may be galvanized, wrought, or cast, the first-named being preferred for oak laths. Iron nails are often objected to on account of their rusting and staining the work. Zinc nails are used, but are expensive. The nails vary from $\frac{3}{4}$ inch to $1\frac{1}{4}$ inches in length.

The heading joints of laths must be broken about every foot, and should be butt-jointed and must not lap over each other.

The laths when prepared should be split or rent from the log, and not cut with the saw, in order to obtain continuous fibres throughout their length. They are made in three thicknesses, and are known as "single laths," "lath and half," and "doubles," the first being $\frac{3}{16}$ inch thick, the second $\frac{1}{4}$ inch thick, the third $\frac{3}{8}$ inch thick.

Counterlathing and Brandering.—It is imperative in all lathed work that the key of the plaster should not be interrupted for a greater distance than 2 inches. Where the laths cross timbers of a greater thickness than 2 inches, the key may be obtained as follows:—

First, by counterlathing, that is, nailing laths to the thick timber members in the direction of their length, and over these nailing laths in the ordinary manner; by this method the key is not interrupted for a distance greater than the width of a lath. Secondly, by brandering, which consists of nailing fillets, from $1'' \times 1''$ to $1\frac{1}{4}'' \times 1\frac{1}{4}''$ at a distance of 1 foot from centre to centre at right angles to the length of the joists, over the whole area to be lathed; then nail the laths to the fillets in the ordinary manner. This method is especially applicable to cases in which the main timbers are spaced apart a distance exceeding 14 inches, which is the greatest permissible span for a lath.

Wire Netting and Perforated Sheet Iron are now used instead of wood laths to receive the coats of plaster and to resist the action of fire, which they do with satisfactory results for partitions, girders, ceilings, etc. These materials are fixed to iron or steel members by wire or hoop iron passed round them or by nailing to wood cradling pieces.

Coarse Stuff is the material generally used for the first and second coats of internal plastering, whether on lath work or brick work. It is composed of good chalk lime, coarse clean sharp sand, and long clean ox hair. It is prepared as follows:—The sand is arranged in a large hollow circle forming a basin about 18 inches in depth for the reception of the lime. It is essential for plastering that the lime should be thoroughly slaked, for should any particles of underburnt or overburnt lime which slakes slowly be introduced into the finished work, they will on slaking blow out small portions of the finished surface. To ensure thorough slaking, the lime is placed in a tub of water and well broken up and mixed; this compound is bailed out with a pail and passed through a fine sieve into the sand basin, thus reducing the lime lumps to a fine state of division; the

remainder (which consists largely of underburnt and overburnt lumps) which does not pass through the sieve is thrown on one side and not used for plasterer's work. The hair, being in its ordinary commercial state in clotted lumps, must be thoroughly beaten to separate it, but not to break it. After beating, it is distributed in the required proportion over the slaked lime; the whole is then thoroughly mixed together with a larry, then heaped and left to temper at least a fortnight before using.

Good coarse stuff may be made by grinding brick rubbish in a mortar mill, and adding lime. The lime should be slaked and strained before being put into the mill, and the hair should on no account be put into the mill. The lime and the ground brick grit must now be turned out and the hair mixed. This is a matter of great importance, for if the hair gets ground up it might just as well have been omitted.

The proportions usually given for coarse stuffs are 1 of lime to 2 or 3 of sand by measure, and 1 lb. of clean long ox hair to every 3 cubic feet of coarse stuff.

One coat work on laths is known as lath and lay, or lath and plaster one coat. Two coat work as lath, lay and set, or lath, plaster and set. Three coat work as lath, plaster, float and set, or lath, lay, float and set. If laid on walls, the first coat is called rough rendering, the second and third coats floating and setting coats respectively, as in lath work. The floating coat consists of spreading a coat of coarse stuff over the pricking-up coat to produce a plane surface.

Putty.—This is pure slaked lime. It is prepared as described in the paragraph on Coarse Stuff. It is usually run into a wood bin instead of a sand basin, and is used in the preparation of setting stuff.

Fine or Setting Stuff.—Fine stuff consists of putty with

the addition of fine sand, generally in the ratio of 1 of putty to 2 of washed sand. The reason for using a setting coat is to obtain a hard surface, for being a thin coat it can easily enter into combination with the CO_2 of the atmosphere, and more perfectly crystallize.

Pure Keene's or Parian cement is used as a setting coat about $\frac{1}{8}$ inch in thickness, instead of the fine stuff; but the pricking-up and floating coats underneath such setting coats should be made of Portland cement and sand, usually in the ratio of 1 to 2, the sum of the thicknesses of the two coats being about $\frac{3}{4}$ inch. Sometimes the pricking-up and floating coats have for their matrix respectively coarse Keene's or Parian cement instead of Portland; but these are more expensive, neither is the key formed to laths nor the adhesion to brickwork so efficient. Lime should not be used as the matrix for the first nor second coats under the same.

The salient angles of plastered walls require to be made stronger than the body of the plastering, being more likely to be chipped. They may be formed with Keene's or Parian cement, making the adjacent covering from 4 to 6 inches each side of the angle, or the sharp angle may be rounded in cement. Steel angles of small section are also used for this purpose. In inferior work the angles are sometimes formed with wooden staff beads.

Gauged Stuff may consist of coarse stuff, putty, or setting stuff mixed with plaster of Paris. The rapidity with which gauged stuff sets when a sufficient quantity of plaster is used enables the plasterer to lay on several coats of internal work in rapid succession. The ratio of plaster of Paris used with these other ingredients varies greatly, ranging from about 1 to 4 down to about 1 to 20 in setting stuff of the other compound. It is largely used for ceilings, cornices, and other mouldings.

Plaster is the term more particularly given to calcareous compounds, the base of which is calcium sulphate.

Plaster of Paris consists of calcined gypsum (calcium sulphate) ground fine; it is generally used in combination with putty; but for castings and enrichments it is used pure. This plaster should be used quite fresh, as it rapidly absorbs moisture from the air, and deteriorates. There are three qualities in general use, viz., coarse, fine, and superfine. The fine and superfine are but little used, except in casting, stopping joints, and sticking up enrichments; for running mouldings, coarse plaster is preferable to fine, in addition to being cheaper. The usual method of gauging plaster is to sprinkle the plaster rapidly and evenly into the water, not to add the water; it is then well stirred, and if this is carefully done, the gauge is free from lumps. The increase in bulk is very considerable, and sometimes causes inconvenience; but the amount of the plaster used with a quantity of putty is comparatively small, therefore the increase of the compound is slight.

Fibrous Plaster, or stick and rag work as it is termed, is a preparation of plaster of Paris on canvas, or canvas and wood backing. It is made in the form of slabs—about 2 feet square for ceilings and partitions, to which it is affixed by nails—and also as mouldings, cornices, casings for columns, etc., which only require the joints to be made good on the building, thus saving the unavoidable delays necessary for the drying of different coats of plaster; it has also the advantage of being a much cleaner method, and is now extensively used.

Keene's Cement is used as a finishing coat in plastering, and is prepared by mixing gypsum with a solution of alum, and then baking it to drive off the water. It is made in two qualities, the coarse and the superfine, and where applied as a plaster sets very hard within a few days, and

is suitable for skirtings, angles, etc. The superfine is white, and is capable of receiving a high polish; the coarse is of a pinkish tinge, will not take such a good polish, but sets with a very hard surface. Where applied to brickwork the rendering coat must be in Portland cement.

Parian Cement is a white cement made by mixing gypsum with borax, and then calcining. It is made in two qualities, coarse and superfine. This cement sets rapidly in four or five hours, does not effloresce, and forms a translucent hard surface. It is used for large surfaces, as it works freer though not fatter than Keene's or Martin's cements.

Martin's Cement is a white cement made by mixing gypsum with potassium carbonate, hydrochloric acid being sometimes added; it is made in three qualities—coarse, fine, and superfine. It will cover, bulk for bulk, a greater surface than either Keene's or Parian cements.

Keene's, Parian and Martin's cements are used for internal plastering work.

Sirapite.—This is a patent plaster, composed chiefly of sulphate of lime and carbonate of lime with other constituents, which latter give to it the peculiar characteristics—rapidity of setting, rapidity of drying, hardness greater than ordinary lime plaster—that it is unnecessary to have Keene's cement for angles; if required it is easily brought to a polished face—does not blister nor blow, does not crack if the timbers do not give, can be used satisfactorily with sawn laths, adheres readily to Fletton bricks; it is laid on and finished in two coats instead of three. In many districts the cost is less than the ordinary three coat work.

The setting is so rapid that it is necessary for good results that a competent plasterer should manipulate this material. The rapidity of its setting precludes its use for

the running of cornices and moulded bands, its non-porosity when finished to a polished surface causing moisture to condense on the walls, therefore polished surfaces should be prohibited.

The first coat on walls is composed of one measure of sirapite to two or three of good clean sand, for lath work, two of sirapite to one of good clean sand. The second to be of sirapite only, applied as soon as the first coat is sufficiently firm. A small quantity of pure lime putty may be used with the first coat. The sirapite should be mixed in small quantities, should not be used on permanently damp walls, should be used fresh from the works; if stored, should be kept in a very dry place; the work should be thoroughly dry before being decorated. The thickness of the two coats on level work should not exceed three-eighths of an inch, which is an advantage for ceilings, compared with the ordinary three coat plaster work of three-quarters of an inch.

Selenitic Lime.—This is fully described in the chapter on Limes and Cements.

Sand.—All sand to be used for plastering should be clear from clay or loam, for the presence of a very small quantity of either of the latter foreign matter would very much weaken the compound and reduce its setting powers. Sand is rarely found in the required condition, hence it nearly always requires to be washed, a small quantity being placed in a sieve and turned to and fro in a tub of water. For the first coat the sand may be washed through a sieve having about sixteen meshes to the square inch; for fining and for finishing mouldings, a sieve having from 256 to 576 meshes to the square inch, according to the degree of finish required. For the finishing off of Portland cement work, a mixture of ordinary sand, and either silver sand or stone dust with the Portland cement is used. Pit sand is sharper than river sand, and is best for Portland cement.

River sand, which is fine and of a light colour, is preferred for internal plasterer's work, the matrix of which is lime or Keene's cement.

Rough Cast is the name given to the product of the operations of plastering on external walls where the first and second coats consist of coarse stuff evenly spread, and upon the latter rough cast (which consists of sand, grit, or washed gravel mixed with hot lime) is thrown in a semi-fluid state with large trowels from buckets upon the newly-covered small and wet portions of the second coat, forming a rough adhering crust, which is at once covered with lime and ochre. It is a method very much applied in half-timbered work.

Pebble Dash consists in first rendering or pricking-up a surface with coarse stuff or Portland cement to form a ground. The second coat is then applied in small sections, on to which is thrown fine washed gravel till the whole surface is covered with the gravel. The gravel is pressed in with a large trowel to ensure the stones being properly embedded; this operation is repeated till the whole surface is covered.

Stucco is the name given to calcareous compounds, the base of which is calcium carbonate free from sulphates. Compounds of this nature set slowly, thereby admitting of modelling *in situ* and fresco work, and the term is now usually applied to calcareous coverings of walls which are intended to be thus treated.

Artificial Marbles are produced by working colours in with white cements or plasters. The following is a description of Scagliola and Marezzo, the two artificial marbles mostly used:—

Scagliola.—Scagliola is an imitation marble, formed of

Keene's cement mixed with various colouring matters, added while the cement is in a soft condition.

It is principally used for panels, pilasters, and columns, which are constructed in the following manner:—A backing is formed of pieces of wood, to which laths are attached. This is covered with a coating of coarse Keene's cement, which, while in a soft condition, is scored with a nail in such a way as to form an undercut key for the next coat, the scorings being made zigzag and parallel, not crossed. When this is dry, the second and final coat is added, being previously coloured as stated. This when dry is rubbed over with a fine uniformly grained piece of stone to level the surface, after which it is successively rubbed with snake-stone and some fine grained hard stone to polish the surface. At this stage a thin slip of Keene's cement—that is, the latter mixed with water to a fluid condition—is rubbed over the surface to fill any pores; when this is dry, the surface is restoned until the required finish is obtained. The surface is finally rubbed over with fine linen rag and linseed oil.

Marezzo.—This is an imitation marble formed of pure Keene's cement, coloured and used for similar purposes to scagliola. It is formed upon a sheet of plate-glass, or any other smooth surface, the process being as follows:—Threads of manilla grass, floss silk, or any other fibres are dipped into a slip of Keene's cement, coloured to the tint of the veining; these are arranged upon the surface mentioned to form the markings. Another thin coat of slip, tinted to the body colour of the marble imitated, is now poured on, the threads are then carefully picked out, leaving behind them the colour of the veining. Dry Keene's is now sprinkled on to absorb the superfluous moisture; this forms a coat on which a canvas backing is laid to strengthen the slab, and on this again a coating of cement is added of any

required thickness. The slab when dry is taken off and polished in a similar manner to the scagliola.

Sgraffitto is a system of decorated covering for walls, used both internally and externally, and consists generally of designs in two or three colours, obtained by forming the covering in as many coats as there are colours required, and by cutting away the upper coats where required to a depth sufficient to expose the layer of the tint desired.

The method of operation is as follows:—The joints of the brickwork are raked out and the surface is picked to form a key for the first coarse coating, which consists of about 1 to 3 of Portland cement and sand, the surface of which is pricked up or scratched. When this is dry, a coat about $\frac{3}{16}$ inch in thickness, with which is mixed some pigments of the required tint, is floated; before this is quite dry, a third coat, thinner than the last, is applied, generally of the natural tint of the cement. Before this has set, a drawing of the intended design is traced on the face of the work; the drawing is removed and the outline is cut, and the required portion of the last coat removed; the coloured background is thus exposed. For internal work lime is the material employed.

Fresco Painting is a system of decoration in which pictures are painted on the finished surfaces of walls and ceilings, while still wet, with water colours, which incorporates with them. The colours thus applied are rendered very brilliant and durable if kept free from damp. The walls are first prepared by raking the joints and picking; a pricking-up coat of coarse stuff is then applied. The second or floating coat consists of putty and good sharp washed sand, the surface being brought up perfectly true and smooth; the setting coat, which consists of 1 to 1 of putty and fine washed sand, is then applied of a thickness of about

$\frac{1}{8}$ inch and worked up very smooth. While the plaster is still moist, the drawing is applied and traced on the surface, and on its removal the painting is carried out. The work is performed in sections not larger than can be worked in one day.

Specifications for Plastering.

In War Department specifications for plasterers' work it is specially stated that neither sea sand nor salt water is on any account to be used. This also applies to bricklayers' work.

London County Council.—All laths used for plastering should be sound laths free from sap, but iron or other incombustible laths, wire netting, or other suitable material, to the satisfaction of the district surveyor, may be used.

Plastering or coarse stuff shall be composed of lime and sand, in the proportion of 1 of lime to 3 of sand, mixed with water and hair; but Portland cement, Keene's cement, Parian cement, Martin's cement, Selenitic cement, or other approved cement or plaster of Paris, may also be used for plastering.

The lime to be used must be freshly burned lime.

The sand to be used must be clean, sharp sand, free from loam or earthy matter.

The hair to be used must be good and sound, and free from grease or dirt; 1 lb. of hair to be used to every 3 cubic feet of coarse stuff. Fibrous material, to the satisfaction of the district surveyor, may be used instead of hair; and ground brick or furnace slag, to the satisfaction of the district surveyor, may be used instead of sand.

The setting coat shall be composed of lime or cement mixed with clean washed sand or of cement only.

Clear water only to be used in mixing the materials.

The Portland cement to be used must weigh not less than 90 lbs. to the imperial bushel.

Fibrous slab or other slab plastering of sufficient thickness

and securely fixed, may be used on ceilings, partitions, and walls, to the satisfaction of the district surveyor.

London County Council.—All laths for plasterers' work to be lath and a half out of the best Baltic fir, free from sap, not less than $\frac{1}{4}$ inch thick, butted at joints, the joints frequently broken and nailed with galvanized-iron nails.

The lime to be of approved manufacture, run most carefully to putty at least one month before using, and all unslaked particles carefully removed. The contractor to run the lime and prepare the mortar upon the premises whenever required to do so.

The hair to be sound, long back hair, well beaten, clean, and dry.

The coarse stuff to be composed of 3 parts, by measure, of sand to 1 of lime, and 9 lbs. of hair to be added to each yard cube.

The fine stuff to be composed of 1 part of lime and 2 parts of sand.

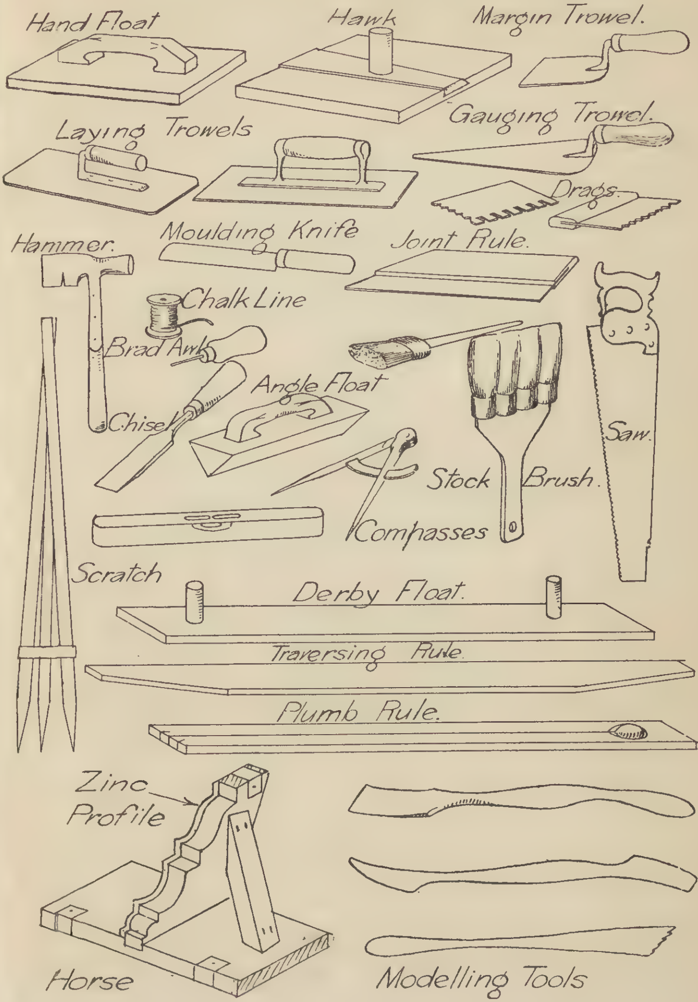
The putty to be composed of equal parts of lime and sand, and a small quantity of plaster of Paris to be added.

The Portland cement to be of the best quality, ground extremely fine, to pass a sieve of 2,500 mesh to the square inch, without leaving a *débris* of more than 10 per cent., and to weigh not less than 110 lbs. per striked bushel filled into a bushel measure as lightly as possible, and capable of maintaining a tensile strain of 350 lbs. per square inch 7 days after being made into a briquette of the usual form, the specimen being immersed in water as soon as it has set and so left during the interval of 7 days.

The sand to be clean, sharp above-bridge Thames or approved pit sand, and to be washed when required.

The Keene's cement dadoes, etc., to be brought out on backings of Portland cement, 4 to 1, finished with fine cement and well trowelled.

All walls described to be plastered, except where other-


Hand Float
Hawk
Margin Trowel.
Gauging Trowel.
Laying Trowels
Drags.
Moulding Knife
Hammer.
Joint Rule.
Chalk Line
Brad Awl
Angle Float
Chisel
Saw.
Stock
Brush.
Compasses
Scratch
Derby Float.
Traversing Rule.
Plumb Rule.
Zinc
Profile
Horse
Modelling Tools

Figs. 1—29.

wise specially directed, are to be rendered in coarse lime and hair, floated with fine stuff and set with putty.

Plasterers' Tools.—Figures 1 to 29 illustrate types of the ordinary tools of the plasterer:—The hawk, for holding material preparatory to depositing upon the surfaces; laying trowels, for laying on the coarse stuff; hand float, used for laying on setting coats; gauging trowel, for mixing gauged stuff; margin trowel, for angles and small spaces where a larger tool would be inconvenient; scratch, used for forming the key in the first coat; angle float, for working up right angles; drags, used to form a key for the next coat, and also for straightening surfaces; joint rule, for working up angles of cornices; hammer, for lathing and general work; chalk line, compasses, level, and plumb rule, for setting out and testing work; saw, for cutting rules and for general work; moulding knife used in making good to work; traversing rule, for forming plaster screeds; Derby float, used for floating material between the screeds; stock brushes, for wetting plane surfaces and moulding during their formation; horse, for running mouldings, a tool specially made for each varying section. There are varieties of each of the previously mentioned tools, also others used for special work, such as modelling, three specimens of which are shown.

STONES.

Classification. — Stones are divisible into three chief classes:—(*a*) Igneous, (*b*) Aqueous, (*c*) Metamorphic.

(*a*) *Igneous* rocks are of volcanic origin, having been formerly in a state of fusion, and include the granites, traps, and syenites.

(*b*) *Aqueous* rocks are those which have been deposited or formed in water or air, and include most of the limestones and sandstones in use for building purposes.

(*c*) *Metamorphic* are rocks of either of the above divisions which in many cases have been subjected to great heat, pressure, or both, sufficient to cause alteration in form, and may be simply a rearrangement of the particles as in clay slate; a crystallization of the constituents such as the marbles; or the addition of new substances from solution in water percolating through rocks and producing new crystalline minerals such as the dolomites.

Stones may be further divided for building purposes into (1) sandstones, or those in which silica constitutes the base; (2) limestones, in which carbonate of lime forms the base; (3) slates; and (4) granites.

Stones are either stratified or granular in structure. The stratified are those sedimentary rocks formed by successive deposits of the materials of which they are composed. The granular are those that have been formed by volcanic agency, or those sedimentary rocks whose original structure has been altered by oscillations of the earth's surface and the action of fire or hot water.

The stratification in good specimens should not be visible to the naked eye, unless through the difference of colour; the grains should also be of uniform size. Such stones are useful for pavings, landings, etc., as they may readily be split along their planes of stratification, called in this case planes of cleavage.

Characteristics of Building Stones.—The salient characteristics of stones will be treated under the following heads:—

General Structure, Fineness of Grain, Compactness, Porosity and Absorption, Weight, Appearance, Seasoning, Natural Bed, and Weathering.

General Structure.—Sandstones consist of grains of sand cemented together by one or more of the following: silicic acid (H_2SiO_3) calcium carbonate, magnesium carbonate, peroxide of iron and clay.

Limestones usually consist of crystallized grains of calcium carbonate joined together by a cement of the same material, and when these are capable of taking a polish are termed marbles; or, as in the oolite, of a number of grains, which are formed of calcareous matter deposited about a nucleus, the latter being usually small shells.

Marbles consist of a crystalline granular aggregate of calcite, white when pure and having the texture of loaf sugar, but passing into various colours according to the nature of the impurities. It occurs in beds among the schists, and is no doubt a limestone, formed either by chemical precipitation or by organic agency and which has been thoroughly metamorphosed by heat and pressure into its thoroughly crystalline character. Some of the fossiliferous limestones through which the Christiania granite rises have been changed into marble, which is a crystalline solid, but their original corals and shells have not been wholly effaced.

Dolomites are stones in which the chief constituents are calcium carbonates and magnesium carbonates in nearly equal quantities. These are compact, crystalline, and oolitic in structure, and are superior to ordinary limestone.

The consolidation of these materials into solid rock has been accomplished by some or all of the following causes:—Pressure of overlying water or rock; partial solution or redeposition; and heat, either dry or moist.

Freestones are granular in structure, with no planes of cleavage, and therefore no tendency to split in any direction, and for that reason are useful for carved work.

Fineness of Grain.—Fine-grained stones are in great demand for carved or moulded work, as it is possible from

these to obtain much finer arrises than from the coarser grained varieties. Such stones depend for their durability upon the extent of the crystallization of the particles, and the quality of the cementing material; but if the particles are amorphous and of an earthy appearance, they are bad, and will be readily disintegrated by any of the destructive agents.

Compactness.—Stones also depend for durability to a large extent on the compactness of the particles or density of the stone. For this reason the best building stones are those of the older formations found at a great depth, and having been subjected to the enormous pressure of the earth above. These stones are often found near the surface, due to alterations of the earth's crust from internal causes, such as volcanic eruptions, earthquakes, etc., or to denudations from external changes due to wind, running water, glaciers, etc., which wear away the upper crust of the earth, and expose the rocks of the older formations.

Porosity and Absorption.—All stones are porous, but some to such an extent as to render them unfit for building purposes, especially for structures in exposed situations, although the constituents and cementing material may be of a durable character.

Porous stones may be destroyed in one of two ways, or by both ways combined:—(*a*) by decomposition, (*b*) by disintegration.

Porous stones absorb much rain-water, especially when the faces of the buildings are exposed to the prevailing winds.

(*a*) Rain-water in its descent takes up some of the acids present in the air; these acids, chiefly sulphuretted hydrogen (H_2S), hydrochloric acid (HCl), and sulphurous acid (H_2SO_3), exist in appreciable quantities in large and manufacturing towns. The rain lodges on the surfaces of the stones into which it soaks, being often driven in

by the wind; the acids combine with the constituents of the stones, dissolve them and cause the stones to crumble.

(*b*) In winter time, the water thus absorbed by the stone freezes, expands, disintegrating the particles and detaching portions of the surface. The adhesion of the particles in some stones is sufficient for a time to resist the expansive force of water when frozen; but even these give way in time to the action of successive frosts, especially when added to this force the stones are subjected to the effects of acids.

Stones should be tested for porosity by soaking samples in water, and noticing the amount they absorb.

Sandstones should not after twenty-four hours' immersion absorb more than 10 per cent. of their volume of water; limestones not more than 17 per cent.; granites not more than 1 per cent.

Weight of Stones.—The weight of stones should be taken into account, and they should be selected to suit the work to be executed. Heavy stones are required for buttresses, retaining walls, and marine structures, while for vaulting and similar work light stones are preferable. Weight is also an indication of the density, and therefore the porosity of a stone.

Appearance.—In the choice of a stone for a building the colour is a good guide as to durability. Highly-coloured stones are often preferred for their architectural effect, frequently at the expense of their durability. The red and brown shades of colour in all the sedimentary rocks are due to oxide of iron, which, if present in large quantities, is apt to disfigure the face of the stone by rust stains, and also leads to rapid disintegration; therefore, the lighter shades of any particular stone should be preferred to the darker tints. There should be no clayholes, bands, or spots of

colour whatever, but the stone should be uniform in colour and in structure.

Seasoning.—All stones when freshly quarried contain a quantity of moisture known as quarry sap, which renders the stone soft and makes it easier to cut; therefore all work should be placed upon the stone as soon as convenient after quarrying.

Stones gain considerably in hardness by being seasoned.

Stones when once worked to a finished surface should not afterwards have their dressed faces disturbed, as is often done on the cleaning down of a building; but should be, when bedded, covered with a wash of plaster of Paris and lime in about equal proportions, which latter can be easily washed off and with it all the dirt and stains incident to building work, as the quarry sap when drying out leaves a hard crystalline skin on the face which will weather considerably better than any fresh face formed after the removal of the original worked surface. This applies with especial force to limestones.

It is important that the sap should be expelled before the stone is placed in a building, because when fixed it cannot dry out so quickly, thereby making it subject to disintegration by frost, easier for acids to act upon it, and being in a soft condition it is liable to break should any great weight be placed upon it.

Stones should therefore be left, after quarrying, to season for a considerable time, which is best accomplished by leaving them in the open air, in order that they may be freely acted upon by the sun and wind. They are often placed under cover in a shed with no walls to allow a free access of air and to protect them from rain.

Natural Bed.—The natural bed in a stone is that surface on which the material was originally deposited, but is not

necessarily horizontal as it rests in the quarry, the strata being often inclined and even upright, due to the beds having become folded and disturbed by volcanic and other agencies.

The purpose for which a stone is used determines the position of the natural bed, as this has an important effect upon its durability. Stones must be arranged so as to obtain—first, the maximum strength to resist crushing; and secondly, to offer the greatest resistance to disintegration by frost. This is done in the following manner:—(1) By placing the stone so that its laminæ are at right angles to the pressure, because the stone is much stronger for weight-carrying purposes when in that position than when the pressure is applied to the end grain of the stone; (2) if the laminæ of the stone be placed parallel to the face of the building, they will scale off successively from the effects of each succeeding frost, every lamina that peels off exposing a fresh face. The stones must therefore be placed with the edges of their laminæ at right angles to the face of the wall.

In walling, such as ashlar work, the laminæ are placed horizontally.

In strings and cornices, with undercut mouldings, the laminæ should be placed vertically, as if placed horizontally the laminæ would be likely to scale off. This principle cannot be carried out in the quoin stones of cornices and strings; if it were so bedded, the whole projection on the return face would after a few years have crumbled away. Such stones must be specially selected and be without any apparent stratification, and laid on their natural bed. Cornices bedded with their laminæ vertically should be covered with lead, as water is readily conducted between the layers.

The laminæ in arches should be placed parallel to the centre line of the voussoirs, and at right angles to the face of the arch.

In good qualities of stratified stone the beds are not

easily discernible, and require a practised eye to determine their direction. They may be easily detected in some stones by thin bands of a greenish or blackish colour of vegetable origin. The beds may often be determined by pouring a little clean water on the stone and noticing the direction it takes in descending. If the stone be examined through a powerful magnifying glass, the particles of which the stone is formed will sometimes be observed to be on their wide flat surfaces, and these flat surfaces are usually parallel to the bed of the stone; the planes of the minute flakes of mica occurring in most sandstones indicates the natural bed, and will be observed to lie in one general direction.

Weathering.—The weathering of a stone is the extent to which its face will resist the action of the weather.

It will be noticed that those faces exposed to the prevailing wet winds (south-west in England), and those that get most saturated with rain, are the faces that show the signs of decay to the greatest extent, also shady parts, such as the underside of cornices, etc., that are at no time exposed to the sunlight, and which never get the moisture dried out of them, being consequently left to the rain with all its attendant defects.

The best way to determine the weathering qualities of a stone is to inspect buildings in the neighbourhood of the quarry that have been built with the stone in question, and also any faces of the quarry that have not been used for a great length of time, and observe how they have weathered. If the stone be required for a building in a large town, this will not be sufficient data to judge of its weathering qualities, but a chemical test as hereafter described will be necessary.

Constituents of Stones.—In order to understand the chemical action of the atmosphere upon stones, a knowledge of the constituents of stones is indispensable.

The composition of the principal classes of stones used for building work is given in the following order below:—Granite, sandstones, limestones, slates.

Granite.—Typical granite is composed of quartz, felspar, and mica; the latter is frequently present in but very small quantities, with occasionally another mineral (hornblende).

Syenite.—Typical syenite is composed of felspar and hornblende.

Hornblendic Granite.—Those rocks containing the four minerals—quartz, mica, felspar, and hornblende—are termed hornblendic granite.

Basalt is a compact black rock, consisting chiefly of felspar, augite, olivine, magnetite, and titaniferous iron embedded in glass or crystallites.

Sandstones are composed of grains of silica cemented together by calcium carbonate or by silicic acid. Nearly all sandstones contain oxide of iron, to the presence of which they owe their colour. Besides these, sandstones often contain mica and clayey matter.

The stone may consist of grains of sand cemented together by lime or other material; the durability of the stone here depends on the quality of the cement, as the sand is indestructible; or, secondly, it may consist of particles of calcium carbonate or other substances joined together by a siliceous cement, in which case the grains are likely to decay, leaving only the cement, resulting in a porous stone. The most durable sandstones are those formed of grains of silica, cemented together by silicic acid, with but a small quantity of other matters, such as the Cragleith, which contains about 98 per cent. of silica and only 2 per cent. of impurities.

Limestones consist chiefly of calcium carbonate, with small portions of silica, magnesium carbonate, iron and clay, and are stratified or oolitic in structure.

Stones consisting of calcium carbonate and magnesium carbonate in nearly equal quantities are known as dolomites or magnesian limestones. Where these two compounds exist in stones in a crystalline condition, the stone is very durable.

Limestone also exists as gypsum or calcium sulphate, in a crystalline condition as alabaster, and is burned largely for plaster.

Slates are obtained from the Devonian, Silurian and Cambrian strata. It is a compact, fine-grained argillaceous rock that has been subjected to enormous pressure, and also to a shearing action which has caused planes of cleavage, independent of the original beds, often crossing them at a great angle. It is on these planes of slaty cleavage, as they are called, that the value of slates depends, as this enables them to be split with facility into thin laminæ, and thus form a light covering. They are composed chiefly of silica and alumina.

They vary in colour from purple to green, and are used in all parts of the kingdom for roofing purposes.

Characteristics.—A good roofing slate should be uniform in colour and free from patches, compact and sonorous, incapable of absorbing or retaining much water, hard and rough to the touch; those which feel smooth and greasy, or are purple in colour, being usually inferior for roofing purposes.

Tests.—A common test for roofing slates is to place one on edge to half its depth in water for twelve hours. If the water approaches the top of the slate it should be rejected; if it does not rise beyond $\frac{1}{8}$th of an inch, it may

be considered as practically non-absorbent. Another method is to weigh a well-dried slate, and after soaking for twelve hours in water to weigh it again; the difference in weight will show the quantity absorbed.

A good slate after twelve hours' soaking should not have absorbed more than $\frac{1}{200}$th part of its weight.

Chemical Composition.—The following is the chemical composition of the principal constituents of stones:—

Quartz is silicon oxide (SiO_2); it is practically indestructible, and is often found coloured owing to the presence of small quantities of impurities, generally metallic oxides.

Felspar is a silicate of aluminium, with silicates of sodium and potassium or calcium $(Na,K)_2O \cdot Al_2O_3 \cdot 6SiO_2$; the K may be replaced by equivalent quantities of Ca, Mg, or Fe(ous). It often contains small quantities of oxide of iron, on which ingredient the colour of red granites depends. If it contains a large proportion of calcium, sodium or potassium, it will be liable to decay.

Mica is found in thin, hard, transparent plates or laminæ, which readily split; it consists chiefly of silicate of aluminium with potassium, the formula $K_2HAl_3(SiO_4)_3$. It imparts the glistening appearance to granite, is readily decomposed, and in large quantities is a source of weakness.

Hornblende is a silicate of calcium and magnesium. These two constituents being in varying proportions, $5(Mg,Ca)O \cdot 6SiO_2$; it is very heavy and of a black or green colour.

Silicic Acid.—$(H_2O)_x(SiO_2)_y$ forms the best cementing material for all sandstones.

Augite is a similar substance to hornblende, $(Mg,Ca)SiO_3$.

Calcium Carbonate.—The basis of all limestones, $CaCO_3$.

Magnesium Carbonate.—$MgCO_3$ exists in numbers of limestones. When in the following proportion the stone is called a dolomite: $54CaCO_3 + 46MgCO_3$, or $(Ca,Mg)CO_3$.

Gypsum is a hydrated calcium sulphate, $CaSO_4 . 2H_2O$.

Alumina.—Al_2O_3 is an oxide of the metal aluminium; combined with silica it forms the basis of clay.

Kaolin.—$Al_2O_3 . 2SiO_2 . 2H_2O$. is a pure white clay derived from the decomposition of felspar, which has been acted upon by water containing carbonic acid, which latter dissolves the calcium, potassium, and sodium, leaving the silica, alumina, and water.

Chemical Tests.—Immerse a few chippings of the stone in a 5 per cent. solution of dilute sulphuric and hydrochloric acids for three days. When taken out and dried the surface grains should still be firm and the angles sharp. Loose sand about the surface would indicate a speedy dissolution in a town atmosphere.

A few drops of the pure acids dropped on to a sandstone would, if effervescence took place, indicate calcium carbonate as a constituent, probably as the cementing material. Such a stone would not weather well.

The following is a list of the stones most largely used:—

LIMESTONES.

Ancaster.—An oolite quarried in Lincolnshire. Composed of:—

Calcium Carbonate	93·59
Magnesium Carbonate	2·9
Iron and Alumina	·8
Water and loss	2·71

It has a specific gravity of 2·182. The colour varies from a white to yellow and pink. Most of the Lincolnshire churches are built of this stone; it is used for local building

work generally, in London and the Midland counties for dressings to doorways, windows, etc.

Box Ground, Corsham, and Coombe Down are varieties of the Bath oolite. Composed of:—

Calcium Carbonate	94·52
Magnesium Carbonate	2·5
Iron and Alumina	1·2
Water and loss	1·78

It has a specific gravity of 1·839. Varies from a light cream to a yellow colour. Of the three the Box Ground is the best weathering stone. It is largely used for dressings, carved and moulded work.

Bath stone to endure must be kept dry and be laid on its natural bed.

Fine-grained Corsham is good for interior work and external work well above the ground level. In the six months of winter the stone is dug and stacked under ground, and is then brought to the surface and seasoned for a period such as six months before being used.

Box Ground is good in all situations, but if used for walls must be at least 18 inches thick to prevent damp passing through. It is quarried in the severest weather, and withstands all injury from the weather. Exposure causes the quarry sap to evaporate, and the stone hardens, and therefore gets more difficult to work.

Portland.—An oolite from the Isle of Portland. Composition as follows:—

Silica	1·2
Calcium Carbonate	95·16
Magnesium Carbonate	1·2
Iron and Alumina	·5
Water and loss	1·94

It has a specific gravity of 2·145. The colour varies from a white to a light brown, the latter being considered the

better. There are four beds of Portland, the true Roach, Whitbed, bastard Roach, and Basebed, the Roach and Whitbed being the best. Portland stone is used for building work generally, and is found to weather better than all other limestones for large towns.

There are three districts in Portland—Wakeham, Minesthay, and Weston—which supply stone in marketable quantities. Their properties seem generally to vary considerably. The first is good to withstand atmospheres charged with sulphuretted hydrogen, such as Birmingham; the second lasts well in sea-coast districts, such as Eastbourne and Portsmouth, and stands well in London. Stone from the third district is good in moist and forest atmospheres, and especially north and west of England and Ireland; for important buildings it would undoubtedly be wise to consult the quarry owner in the selection. Although it is safe to lay Portland stone on its natural bed it is not so important as in Bath and other limestones.

Ham Hill is obtained from Somersetshire. Composition as follows:—

Silica	4·7
Calcium Carbonate	79·3
Magnesium Carbonate	5·2
Iron and Alumina	8·3
Water and loss	2·5

Specific gravity 2·26. Colour, yellow and grey; the first is bright when first quarried, but tones down. Used for facings and dressings, weathers well.

Chilmark.—A brown oolite, obtained from Wiltshire. Composition as follows:—

Silica	10·4
Calcium Carbonate	79·0
Magnesium Carbonate	3·7
Iron and Alumina	2·0
Water and loss	4·2

Specific gravity 2·481. Light brown in colour. Very durable. Used for general building, specially suitable for steps and paving, and much used for heavy engineering work.

Doulting Freestone.—An oolite of uniform texture, obtained near Shepton Mallet, Somersetshire. Composition as follows:—

Calcium Carbonate	95·89
Magnesium Carbonate	·11
Alumina	·79
Sesquioxide of Iron	·85
Silica	2·04
Water	·32

Specific gravity 2·45. It varies from a cream to a brownish-yellow colour. It is very durable, and suitable for general building work.

Hopton Wood.—A fossil limestone quarried in Derbyshire, takes a good polish; used for ornamental paving, wall panels, and decorative purposes.

Little Casterton.—An open oolite quarried near Stamford; used locally for general building purposes.

Purbeck Marble.—From the upper oolite beds, quarried at Purbeck, in Dorsetshire. Mottled grey in colour, takes a fine polish; much used for internal church work, being suitable for slender columns and decorative work.

Caen.—A fine oolite quarried at Caen, in Normandy. It has been largely imported into England, but is a failure for external work, as it weathers very badly, but is much used for internal work for decorative purposes, being well adapted for carving.

Maningham.—A sandy limestone quarried near Boulogne, in France, suitable for pavements. Is not largely used in England.

Magnesium Limestones.

Anston.—Quarries near Sheffield,. Yorkshire. A magnesium limestone from the Permian bed, is a fine granular crystalline aggregate with cavities. Dispersed through the mass are black particles apparently carbon. This is probably not an altered limestone, as the structure of the stone indicates precipitation from chemical solution. It is of a rich cream colour. Weight when dry 141 lbs. 3½ ozs., when wet 148 lbs. 14½ ozs. per cubic foot. It has been largely used in the Houses of Parliament, Westminster, Geological Museum, Piccadilly, and the Record Office, Chancery Lane. The beds are from 1 foot to 2 feet 6 inches thick, and they are most durable when laid on their natural bed. Test pieces of this stone cracked slightly with 815·6 tons, and crushed at 833·1 tons per square foot.

Bolsover.—From Derbyshire. Composition as follows :—

Silica	3·6
Calcium Carbonate	51·1
Magnesium Carbonate	40·2
Iron and Alumina	1·8
Water and loss	3·3

It has a specific gravity of 2·267. Light yellowish-brown colour. Good durable building stone, also useful for paving.

Mansfield Woodhouse.—Obtained from Nottinghamshire. Composition as follows :—

Silica	3·70
Calcium Carbonate	51·65
Magnesium Carbonate	42·60
Water and loss	2·05

Specific gravity 2·33. Yellow colour. Much used for internal decorative work, does not stand well externally.

Huddlestone.—Quarried at Sherburn in Yorkshire. Composed as follows:—

Silica	2·53
Calcium Carbonate	54·19
Magnesium Carbonate	41·37
Iron and Alumina	1·3
Water and loss	1·61

Specific gravity 2·14. Cream colour. Suitable for general building purposes.

Roche Abbey.—Quarried near Bawtry, Yorkshire. Composed as follows:—

Silica	·8
Calcium Carbonate	57·5
Magnesium Carbonate	39·4
Iron and Alumina	·7
Water and loss	1·6

Specific gravity 2·14. Light cream colour. This stone is suitable and is much used for general building purposes, but is subject to discoloration.

Park Nook.—Quarried near South Milford, Yorkshire. Composed as follows:—

Calcium Carbonate	55·7
Magnesium Carbonate	41·6
Iron and Alumina	·4
Water and loss	2·3

Has a specific gravity of 2·13. Cream colour. Moderately good building stone, much used locally.

SANDSTONES.

Cragleith.—Quarried near Edinburgh. Composed as follows:—

Silica	98·3
Calcium Carbonate	1·1
Iron and Alumina	·6

Specific gravity 2·232. Whitish-grey colour. Very hard and durable, good for ashlar and general building purposes.

Specially suitable for landings, steps, etc. This quarry is nearly worked out.

Hailes.—The stones from these quarries near Edinburgh, in the neighbourhood of Cragleith, are of three tints, white, pink, and bluish grey.

The white rock appears, from its more complete secondary silicification, to be the strongest and most compact in structure of the three varieties. The small percentage of iron and of the ferrous compounds points to a probability of greater immunity from discoloration and liability to rust stains than the blue rock. It is finer in grain and on all accounts to be preferred to the blue rock. The following gives the analysis of the white rock :—

Silica	96·52
Lime	·409
Sodium Oxide / Potassium Oxide	·27
Ferrous Oxide	·19
Ferric Oxide	·056
Alumina	2·78
Loss on ignition	·31
	100·535

The blue rock has the most marked lamination, and the cementitious matter is partly aluminous. The blue colour is due to fine lines of carbonaceous matter. The following is the analysis :—

Silica	92·23
Lime	·81
Magnesia	·19
Sodium Oxide / Potassium Oxide	·18
Ferrous Oxide	1·71
Ferric Oxide	·013
Alumina	2·93
Loss on ignition	1·73
	99·793

The pink is a variety having properties intermediate between the white and the blue. The following is the analysis:—

Silica	96·7
Lime	·36
Magnesia	trace
Sodium Oxide / Potassium Oxide	·13
Ferrous Oxide	·25
Ferric Oxide	1·46
Alumina	·84
Loss on ignition	·58
	100·32

Stone from this quarry has been used largely in Edinburgh and neighbourhood for the last two centuries, and has proved an excellent weathering stone for general building purposes. It is especially suitable for templates, steps, landings and pavements, and can be obtained in very large blocks. The following test for transverse strength was made on this stone at the New Art Galleries, Kelvingrove, Glasgow. The steps tested were each 11 feet 6 inches long, having a 9-inch wall hold at each end. Three steps were built into walls having a clear span of 10 feet; they were then gradually loaded on top with steel joists till the load reached six tons, when the deflection at centre of steps was $\frac{3}{8}$ths of an inch, and the loading occupied a space of 4 feet in the centre of the steps. The intention was to load until they broke, but when the results were so satisfactory the steps were saved.

Bramley Fall.—Originally quarried near Leeds, but the name is now used to denote the coarse millstone grits of Yorkshire. Specific gravity 2·11. Light brown colour. Very durable and good for general building purposes. Specially suitable and much used for pavings, steps, girder beds, engine beds, etc.

Darley Dale.—Quarried near Bakewell, Derbyshire. Composed as follows:—

Silica	96·4
Calcium Carbonate	·36
Iron and Alumina	1·3
Water and loss	1·94

Specific gravity 2·62. Light brown colour. Good for general building purposes, and is largely used.

Professor J. Shipman, F.G.S., in his report upon the best building stones, says:—"The excellent quality of the stone from the Stancliffe Quarries, Darley Dale, is seen in the entrance lodge and gates of the park (to Stancliffe Hall), which are built of it. The work presents a superbly clean and crisp appearance, the most delicate sculpturing and cornicing standing out as sharp and clear as if it had been chiselled the previous day. The stone is of a light drab or yellowish-white colour, inclining to a very pale greenish tint, but the colour of the stone is so subdued that it is almost white. There are no streaks or blotches of red about it, and its texture is very uniform throughout. When very closely examined it seemed to be a close-grained, finely micaceous grit, the mica occurring in only very minute silvery spangles.

"The rock is a thick-bedded grit, compact and very hard. It has been largely quarried, and is considered by the authorities to be a most valuable stone.

"St. George's Hall, Liverpool, is perhaps the finest example of a building in which this stone has been employed."

Heddon.—Quarried near Newcastle, Northumberland. Composed as follows:—

Silica	95·1
Calcium Carbonate	·8
Iron and Alumina	2·3
Water and loss	1·8

Specific gravity 2·29. Light brown colour. Durable stone, good for general building purposes.

Kenton.—Quarried near Newcastle, Northumberland. Composed as follows:—

Silica	93·1
Calcium Carbonate	2·0
Iron and Alumina	4·4
Water and loss	·5

Specific gravity 2·24. Light brown colour. Good for general building purposes, particularly for fine and carved work.

Grinshill Freestone.—Quarried near Yorton, Shropshire. Composed as follows:—

Silica	95·46
Alumina	1·17
Peroxide of Iron	·87
Calcium Carbonate	·61
Magnesium Carbonate	·69
Water	1·2

Specific gravity 1·96. Yellowish-brown colour. A fine-grained soft sandstone, extensively used for facing and general building work.

Scotgate Ash.—Quarried at Pately Bridge, in Yorkshire. Specific gravity 2·45. Greyish-yellow in colour. It is fine-grained, hard, laminated sandstone, suitable for staircases, pavements, etc.

Howley Park.—Quarried at Morley, Yorkshire. Specific gravity 2·56. Light brown colour. A fine-grained homogeneous sandstone, durable, not hard, used for dressings, stairs, pavings, and general building work.

Robin Hood.—Quarried near Wakefield, Yorkshire. Greenish-grey colour. Durable, suitable for landings, staircases, etc.

Corsehill.—From Annan, in Dumfriesshire. Specific gravity 2·46. Dark red and bright pink in colour, contains about 95 per cent. of silica. Good weathering stone, suitable for carvings, dressings, and ashlar.

Magnesium Sandstones.

Red Mansfield.—Quarried near Mansfield, Nottingham. Composed as follows:—

Silica	49·4
Calcium Carbonate	26·5
Magnesium Carbonate	16·1
Iron and Alumina	3·2
Water and loss	4·8

Specific gravity 2·33. Reddish-brown colour. Oolitic in structure, very durable. Suitable for general building work, carving, moulding, etc.

White Mansfield.—Quarried in the same district as Red Mansfield. Composed as follows:—

Silica	50·0
Calcium Carbonate	41·3
Magnesium Carbonate	7·3
Water and loss	1·4

Specific gravity 2·33. Whitish-brown colour. Similar in all respects to the red variety, but is not considered so durable.

Granites.

Igneous Rocks.—The igneous rocks as used for building purposes consist of granites and basalts which are of a crystalline granular structure.

Quarrying and Working.—In Great Britain granite is chiefly obtained from Cornwall and Aberdeenshire. As the British quarries are insufficient to supply the demand a

great quantity is imported from Guernsey, Norway, Sweden and Russia, but the working of the granite from all parts is chiefly carried on at Aberdeen.

The method of quarrying is as follows:—Blocks are detached by blasting, which are hauled from their position in the quarry by means of steel rope railways to the point at which they are worked. Blocks are roughly squared into suitable dimensions by nicking a line about the stone and sinking small holes about 1 foot apart into which are inserted steel wedges and feathers; these are tapped with a hammer in succession until, the stress becoming too great, the stone is rent through the plane bounded by the nicking. The stones are also roughly faced at the quarries with hammers, and fine faced with hammers and chisels. Large surfaces are now more expeditiously faced with a surfacing machine. The block is placed in position and a large surfacing tool worked by pneumatic power is caused to strike the stone with a series of rapidly delivered blows, the tool being guided by the hand; the surface is gradually worn to a uniform level. Pneumatic chisels are used also for lettering, carving and moulded work. Granite is sawn into slabs by means of toothless steel blades assisted by chilled cast-iron shot, the stones being divided at the rate of about two inches per hour. The stones for polishing are placed on a table and bedded in plaster-of-Paris; the surface is rubbed and polished by means of heavy circular iron rubbers rotating on vertical axes, the table having imparted to it a reciprocating horizontal motion, thus permitting of the entire surface being rubbed uniformly, chilled shot, carborundum, sludge and putty powder being used as mediums to produce the polished surfaces. For moulded work, cast-iron slippers the reverse of the mouldings are caused to work over the members to be polished, which are embedded in plaster to preserve the arrises and mitres. Circular work is turned and polished in lathes.

Classification.—Igneous Crystalline Rocks are usually classified as follows :—

I. Acid rocks, with 65—80 per cent. of silica.

II. Intermediate rocks, with 55—70 per cent. of silica.

III. Basic rocks, with 45—60 per cent. of silica.

IV. Ultra-basic rocks, with 35—50 per cent. of silica.

Granites are included in Group I. Syenite proper, containing felspar and hornblende but no free silica, belong to Group II. Basalts belong to Group III., whilst the rocks of Group IV. are too rare to be used for building purposes.

Stones comprised in the groups other than I. are often incorrectly termed granites.

Grey Aberdeen.—Quarried at several places in Aberdeenshire. Takes a high polish ; suitable for columns and ornamental work ; largely used for kerbs and sets.

Rubislaw.—One of the chief quarries is Rubislaw, near Aberdeen. It is fine grained, grey in colour, and can be obtained in blocks as large as 240 cubic feet. It takes a high polish, is extremely durable and is largely used for constructional, monumental and decorative purposes, and can be obtained in large quantities. The following is its composition, given by Professor Geikie :—

"This rock is a true granite. It contains white and black micas (muscovite and biotite), of which the latter is the more abundant, together with felspars and quartz.

"Of the felspars, microcline is the most prevalent, but plagioclase occurs in fair quantity. Fine needles of rutile are seen in the quartz. Other accessory ingredients sparingly present are zicron, apatite, and magnetite.

"This is one of the most durable kinds of granite."

Pink Aberdeen.—Various shades of this kind are quarried in Aberdeenshire. It answers the general description of the grey varieties.

A noted quarry is that of Corrennie, the stone from

which is of a close grained pink variety and is largely used for constructional and decorative work.

Peterhead.—The stone from this quarry in Aberdeenshire is of a coarse red variety and is largely used for constructional and decorative purposes. Many large polished columns have been executed in this material.

Cornish Granite.—Obtained in various parts of Cornwall. Grey in colour. Is largely used for engineering works, bridges, and similar constructions.

Guernsey Granite.—Quarried in Guernsey. Varies from reddish-brown to a grey-blue colour. It is a syenitic granite containing felspar, quartz and hornblende, and a little mica, used chiefly for paving sets.

Swedish Granite, Victoria Grey.—This rock is quite a normal granitite, and belongs to the acid group and contains orthoclase, biotite, and quartz. Along with these occur a little microcline and micropegmatite, apatite, and zicron. The last-named is enclosed in the biotite, and is surrounded by black halos. Is used for decorative and monumental work.

Finland Granite.—This rock is a fine hornblende—granitite. It has a schistose aspect—a structure which is not seen under the microscope.

The chief mineral constituents are—hornblende, biotite, orthoclase, plagioclase, and quartz.

The accessory and minor ingredients are apatite, magnetite, zicron, and sphene—the last-named being fairly common. The hornblende is green, and the biotite is dark brown. Both occur in small crystals, usually associated, and often well formed. The orthoclase is very fresh and abundant. Plagioclase is not very common. Quartz occurs in fair quantity. Epidote (a secondary mineral, or product of decomposition) is present.

It is a rock of the acid group but more basic than the Victoria grey. Is used for decorative and monumental work.

Norway Granite.—A fine-grained granite quarried in Norway, extensively used for curbstones pitchings; it is preferred on account of the great lengths in which it can be obtained.

Swedish Labradorite.—This is a rock of the intermediate group and is not a true granite. It is a greyish green and very coarsely crystalline rock. To the naked eye it seems to consist chiefly of large felspars, showing some play of colours with a subordinate proportion of dark mica and pyroxene.

Under the microscope the felspars prove to be the varieties known to mineralogists as anorthoclase or cryptoperthite (that is, mixtures of albite and orthoclase).

The other ingredients are dark greyish green augite with dillage-structure, deep brown biotite (mica), magnetite, and apatite, which appears in relatively large crystals. This rock belongs to the class of augite-syenites (known to geologists as laurvikites), which are well developed in Southern Norway. (The rocks referred to are somewhat variable in composition, containing often zicron; occasionally olivine and nepheline, and less commonly quartz.)

Used for monumental and decorative work.

Swedish Bon-Accord.—This is a rock of the third or basic group and is not a true granite.

This rock is an olivine-gabbro. Its constituent minerals are plagioclase, felspar, augite (diallage), and olivine, with a small proportion of black mica and magnetite. This plagioclase occurs in fairly well-formed crystals which are occasionally enclosed in the augite—thus showing a tendency to what is known as the ophitic structure so commonly seen in the rock called diabase. The olivine is very fresh and rather abundant. The black mica (biotite) mostly occurs in the form of scales around the magnetite.

Gabbros of this character occur at Elfdalen, in Sweden.

Used for monumental and decorative work.

Granite does not successfully resist the action of fire or acids.

Porphyritic Granite, Shap Fell.—The stone from this Westmoreland quarry is of a reddish-brown tint and contains large pinkish crystals of felspar, takes a high polish, and is largely used for decorative work.

Weight, Strength and Absorption.—The following is a table giving the weight, strength and absorption of the stones in most general use:—

—	Weight per cubic feet in lbs.	Absorption in percentage of its dry weight.	Crushing load per square foot in Tons.
LIMESTONES—			
Ancaster Freestone	140·4	6·27	184·0
Box Ground	127·9	7·49	97·5
Coombe Down	128·6	5·80	117·7
Corsham Down...	129·0	11·06	94·5
Doulting Freestone	125·0	11·05	103·9
Ham Hill	136·0		166·3
Monks Park	136·7	7·74	139·6
Portland, Whitbed	132·3	7·51	204·7
DOLOMITES—			
Red Mansfield	143·2	4·58	591·9
White Mansfield	140·1	5·01	461·7
Yellow Magnesium Limestone	145·4	4·62	577·4
SANDSTONES—			
Blue Hailes	143·2	4·70	459·7
Bramley Fall	132·2	3·70	238·4
Corsehill	130·4	7·94	444·9
Cragleith	138·6	3·61	861·9
Dean Forest	151·4	2·71	530·0
Darley Top	139·0	3·40	516·7
Howley Park	140·3	4·90	466·7
Robin Hood	144·6	3·90	574·0
White Grinshill...	122·5	7·80	209·3
White Hailes	143·8	3·71	662·0
GRANITES—			
Aberdeen Corennie (Pink) ...	159·1	0·42	1318·3
" Peterhead (Red) ...	158·5	0·29	1207·7
" Rubislaw	163·7		1098·8
Cornish Grey	161·7		955·9

Preservation of Stone.—Of late years, a solution known as Fluate, and prepared by the Bath Stone Firms, has been introduced and extensively used to harden and preserve limestones in new work from decay, and also it is useful in preventing the decay in old work going farther. It does not materially alter the colour nor apparent texture of the stone to which it is applied, but it hardens the face and renders the stone more durable. The work is first cleaned and then the fluate is laid on the face with a brush.

BRICKS.

Definition.—Bricks are an artificial kind of stone, made of burnt or baked argillaceous or clayey earth, and the quality of the bricks depends upon (*a*) the chemical properties of the earth, (*b*) the preparation of the earth, and (*c*) the different degrees of burning or baking.

Composition.—The following is approximately the chemical composition of a good brick-earth :—Silica, three-fifths ; alumina, one-fifth ; oxides of iron, calcium, magnesium, manganese, sodium and potassium forming the remaining fifth.

Clay or aluminium silicate $(Al_2O_3)_x(SiO_2)_y(H_2O)_z$ forms the bulk of brick-earths. It possesses the property of plasticity when damp, but upon the application of sufficient heat it gives off its water, losing its plasticity, and becomes permanently rigid, and by no known process can its plasticity be restored. It contracts and warps during the process of burning.

Silica (SiO_2) is present, either chemically combined with alumina and water, or free in the form of flint and sand. Its presence in clays produces hardness, resistance to heat, durability, and prevents shrinkage and warping. An excess of silica causes bricks to be brittle.

Lime-stone or chalk $(CaCO_3)$, when present in brick-earths, acts chemically in burning as a flux, causing the particles of the bricks to unite, producing greater molecular strength, and in small quantities diminishing contraction.

An excess of calcium carbonate causes the brick, in burning, to melt and lose its shape.

Magnesia (MgO) in the brick-earth influences the colour of bricks.

Iron influences the colour of bricks, but if occurring in clays, as iron pyrites (FeS_2), it should be carefully removed, otherwise it will oxidize in the brick, crystallize, and split it to pieces.

Clays often contain various salts (and those taken from the sea-shore or near salt formations contain a quantity of common salt), which render the clays unfit for the manufacture of bricks, and act as fluxes in burning. When in excess this causes the bricks to warp and twist, in addition to which the bricks absorb atmospheric moisture for a considerable time and cause efflorescence, which is very noticeable on new work.

Analyses.—The following analyses give an idea of the proportions of the chemical elements in some of the brick-earths. Nos. 1 to 7 are from Abney, No. 8 from Knap.

	1	2	3	4	5	6	7	8
	Fire-clays.		Ordinary Clays.					
	Dinas.	Stourbridge.	Loam.	Blue Clay.	Burham Clay.	Terra-Cotta Clay.	London Brick Clay.	Marl.
SiO_2	86·2	63·4	66·7	46·5	42·92	75·2	49·5	43·0
Al_2O_3	2·3	23·2	27·0	38·0	20·42	10·0	34·3	
Fe_2O_3	·3	1·9	1·3	1·0	5·0	3·4	7·7	3·0
CaO	1·0	—	·5	1·2	10·79	1·2	1·4	26·04
MgO	—	·9	—	—	·07	trace	5·1	3·5
Alkalies or Alkaline Chlorides ...	—	—	—	—	·33	·5	—	—
CO_2	—	—	—	—	8·12	—	—	20·46
H_2O	—	—	—	—	6·68	5·9	—	4·0
Organic Matter ...	10·0	10·0	5·0	13·6	5·01	3·7	1·9	—
	99·8	99·4	100·5	100·3	99·34	99·9	99·9	100·0

Very few brick-earths are in such condition as to allow of their being used without some special preparation. They are practically classified as plastic or strong clays, loamy clays, and marly clays.

Plastic or strong clays, known to the brickmaker as foul clays, contain silica, alumina, and but a very small proportion of lime, magnesia, soda, or other salts, and are sometimes described as pure clays. For the manufacture of bricks these clays require the addition of silica and lime.

Loamy or mild clays contain quantities of free silica, and are known as sandy clays. To these calcium carbonate is frequently added.

Marls or calcareous clays contain a large proportion of lime, make good bricks, and are frequently used without the addition of other substances, but lime or sand is added if the natural earth is deficient in these compounds.

Malm or washed earth is a prepared marl in which the quantities of the constituents are proportioned to give the best results, where bricks of a specially good quality are required. The brick-earth is ground to a pulp in a wash mill and mixed to the consistency of cream, with chalk previously ground. It is then passed through a screen or grid which excludes from the mixture any large particles or stones and ensures a fine division of the material, which is then conducted into settling tanks or pits. The particles are allowed to settle and most of the excess of water is run off, and a large portion of the remainder evaporates. The resulting pulp is known as malm. At this period the breeze necessary for the proper burning of the brick is spread over the compound. Frequently malm is mixed with a proportion of ordinary unwashed brick earth: the product is termed "malmed earth."

Test for Clays.—The brickmaking quality of a clay is usually ascertained by making a brick out of the clay in

question, and treating it, exactly as other bricks are treated, by firing it in a brick-kiln. If the brick does not come up to the required standard, chemical analysis will suggest what might be added to improve the earth.

The treatment of brick-earths varies in different brick-yards; the operations are in general as follows, and may be performed by hand or machine:—1st, the preparation of the brick-earth; 2ndly, the moulding; 3rdly, the drying; 4thly, burning.

The following description of the manufacture of three classes of bricks will include the chief methods of brick-making, viz., (1) the hand-moulded clamp-burnt bricks, commonly known as stocks; (2) the machine-made wire-cut kiln-burnt; (3) the machine-made pressed, or hand-moulded, kiln-burnt bricks.

Hand-Moulded Clamp-Burnt.—For this method the earth is subjected to the following processes:—unsoiling; clay digging; stone picking, or washing and screening; addition of chalk, sand and breeze as required, and weathering; mixing; and tempering in a pug mill.

Unsoiling consists in removing the mould or top, which is often used for resoiling exhausted workings. The vegetable mould is known as Encallow, and the operation of removing it Encallowing. Clay digging is usually performed in the autumn, when the clay is excavated and heaped up to the height of several feet on a levelled piece of ground prepared to receive it, any stones being carefully picked out by hand.

A layer of brick-earth is spread upon the ground, upon which is placed a layer of breeze, and then a layer of chalk, which latter has been previously broken up and mixed with water in a wash mill. This series of layers is repeated till the heap is 5 or 6 feet in height. It is then left through the winter months to be disintegrated and mellowed by the frosts.

An alternative process, where a better class of brick is required, is to wash the earth and chalk, if required, together in a wash-mill. The resulting compound, with a considerable quantity of water, is passed through a grid to ensure the particles being in a fine state of division; it is then conducted to settling-pits, from which the excess water is removed When the material is sufficiently firm, a layer of breeze to the required amount is spread over the top, and left during the winter to weather.

In the spring the earth which has been left during the winter to weather is mixed, the heaps being cut in vertical sections to ensure the uniform distribution of the various materials throughout the mass. After being turned over two or three times, it is wheeled away in barrows to be tempered.

The object of tempering is to knead the earth into the proper condition for the moulding process. The usual method (when only comparatively small quantities are required) is to turn the clay over two or three times, kneading and battering it with shovels, and picking out any stones that may remain. Horses or men tread over the same, making the clay into a homogeneous mass. Where the demand for bricks is sufficiently great, the clay is tempered by being passed through a pug mill—a machine consisting of a circular stationary tub with a revolving vertical spindle, to which are keyed a number of knives, which, by their motion, cut, knead, and force the clay gradually through the pug mill, fitting it for the immediate use of the clot moulder.

Moulding.—The object of moulding, which is performed by hand, is to give the brick-clay a definite shape.

The operation of hand moulding consists in placing a wooden or iron box termed a mould, about $10'' \times 5'' \times 3''$ (if the dimensions of the burnt brick are to be $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{5}{8}''$, as the clay generally shrinks about one-tenth in all directions), without top or bottom, over a

stock-board with a fillet or *kick*, about 7″ × 2″ × $\frac{3}{8}$″, fixed upon the same, and forming a projection upon the stock-board, which is secured to the moulder's bench. The mould is either (1) wetted or (2) sanded, so as to prevent the surface of the raw brick from adhering to its sides. The moulder then dashes and presses a clot of tempered clay, which he has immediately before kneaded with his hands, and from which he has removed any stones which may have escaped previous detection. He then takes the strike, which is usually a pine fillet about 16″ × 1½″ × $\frac{3}{8}$″, and draws and pushes off any superfluous clay over and above the level of the sides of the mould.

Drying.—Directly the clay has been moulded the operation of drying commences, the object being the evaporation of all superfluous moisture without damaging the brick—to render it sufficiently hard to be handled without injury, and to enable the raw brick to possess the requisite strength to withstand the pressure caused by stacking in the clamp during the process of burning.

When the method known as slop moulding is employed, the usual routine is for a boy to take the mould and moulded brick from the moulder, and place the raw brick on its bed upon a drying floor, which is slightly convex, and covered by a roof, the bricks are then sprinkled with sand to absorb superfluous moisture. After one day's exposure the raw bricks are placed upon their sides for another day, after which time they are sufficiently hard to be wheeled upon barrows to the hacks. The hacks are long parallel banks, usually 6 inches above the level of the ground, and built of brick rubbish and ashes, or sometimes of agricultural drain pipes at right angles to the length of the hack, and covered with a thin concrete bed, the object of which is to form a smooth horizontal bed thoroughly drained, so as to keep dry and to prevent the damp from rising.

If the method known as sand moulding be adopted, the moulder places a pallet (which is a piece of pine $\frac{3}{8}$ inch thick, and about 1 inch wider and longer than an ordinary brick) upon the raw brick in the mould, then turns the whole over, releases the mould, and places the raw brick on pallet upon a specially made wheelbarrow with springs, so as to reduce the vibration, which is dangerous to the raw bricks; when the barrow is loaded, the bricks are taken and hacked at once.

The bricks are hacked about $\frac{3}{8}$ inch apart (the thickness of a pallet), being laid on a long narrow face and built about seven courses high, their ends exposed to the weather, their wide faces vertical and at right angles to the length of the hack. In that state they remain for about ten days, after which they are scintled, that is, their wide faces arranged vertically and diagonally at an angle of 45° to the length of the hack, the directions of the successive courses being reversed, and a space of about 2 inches between the bricks, so that the wind may get between and more effectually dry them, the whole operation of drying taking from three to six weeks.

During the time of drying, which takes place in the open air, the hacked bricks are protected from the weather by wood framing, covered with straw, matting, canvas screens, or tarpaulins.

Burning.—The object of burning is to drive the water from the clay and thus cause it to lose its plasticity, and to fuse the constituents into a homogeneous body, and to endow it with the necessary degree of hardness to resist compression for the purposes of building, and to vitrify it sufficiently to resist the disintegrating effects of the winter's frosts.

These bricks are burnt in clamps, the construction of the latter being as follows:—The site is raised above the surrounding ground, and to ensure dryness is drained. This

surface is paved with a layer of bricks (generally badly-burnt bricks from a previous burning), upon which a series of horizontal flues, termed fire-holes, are constructed; these flues are filled with faggots. Over these two layers of bricks are laid on edge diagonally and about 2 inches apart, the interstices being lightly filled with breeze; over this a layer of raw bricks on edge is placed close together. Over this is spread a layer of breeze 7 inches in depth, then another course of raw bricks, on which is a second layer of breeze 4 inches in thickness; upon this another course of bricks on edge, then a layer of breeze 2 inches in depth. Above this the bricks are built in a series of bolts (that is, a thin unbonded wall) to a height of 14 feet.

The time of burning is from two to six weeks, according to the number of fire-holes and the atmospheric conditions.

The bricks produced by this method are termed stocks. These are generally employed for the internal parts of the walls of buildings, for which purpose they are eminently adapted, being capable of resisting a great amount of compression, their surfaces forming a very effective key for plastering. Usually the better qualities of stocks are picked for facings, care being taken that as nearly as possible they should be of one tint, showing well-burnt faces.

Stocks are classified according to their quality as follows:—Malms, Malmed, and Common.

Malms.—Cutters, Best Seconds, Mean Seconds, Pale Seconds, Brown Facing Paviors, Hard Paviors, Shippers, Bright Stocks, Grizzles, Place.

Malmed.—Bright Fronts, Stocks, Shippers, Hard Stocks, Grizzles, Place.

Common.—Stocks, Shippers, Grizzles, Rough Stocks, Place, manufactured from unwashed earth.

1. *Cutters or Rubbers.*—Made from washed earth containing sufficient sand necessary for a burnt brick which may

be easily divided with a brick-cutter's saw. The best are burnt to a state little short of vitrification.

2. *Seconds.*—Similar to No. 1, but uneven in colour.

3. *Facing Paviors.*—Hard-burnt malms of good shape and colour, used for facings of superior walls.

4. *Bright Fronts.*—Similar quality, from malmed earth.

5. *Hard Paviors.*—More burnt; slightly blemished in colour; used for superior paving, coping, etc.

6. *Shippers.*—Sound hard-burnt bricks, imperfect in form; used as ballast for ships.

7. *Stocks.*—Hard, sound, fairly uniform in colour; they are used for the mass of ordinary good work.

8. *Hard Stocks.*—Overburnt, but sound; slightly misshapen, and colour not uniform; they are used in footings and in the body of thick walls, and in positions where the work is subjected to a great compressional stress.

9. *Grizzle.*—Underburnt, but sound and of good form; used for inferior or temporary work, and where not subjected to heavy loads.

10. *Place.*—Underburnt, weak; containing stones, causing them to be very liable to breakage; for inferior or temporary work. Sometimes place bricks are used in the panels of brick-nogged partitions for the purpose of retarding sound.

11. *Chuffs.*—The action of wind, frost, or rain upon bricks while hot, on the outside of clamps, causes the bricks to be full of cracks and useless for constructional purposes; also if the bricks are put into clamps before they are sufficiently dried; such bricks are termed chuffs.

12. *Burrs.*—Lumps of bricks vitrified and run together. They are useful for rough walling, artificial rock work, etc.

Stock Bricks, Machine-Made.—Messrs. Eastwood & Co., of Conyer, Kent, have recently introduced a German patent

for the manufacture of stock bricks by machinery with patent drying chambers and kiln. Great care is taken in the proper admixture of the usual materials, which is run with a large proportion of water into settling pits. After the surplus water has been drained off and the prepared earth is sufficiently mellowed by weathering, it is then barrowed into the pug mill, and from thence passed to the moulding machine below, where it is pressed into a mould containing six bricks. Upon removal from the moulds, the raw bricks are placed upon specially-constructed trolleys working upon tram-lines, and conveyed to the drier. This consists of three long chambers, through which the heat is regulated by means of fans, the temperature varying from 45° to 200° Fahr. The bricks by this method are fit for the kiln in 24 hours. For burning, they are then stacked upon specially-constructed trolleys running upon a tramway. The upper portions of the trolleys for a considerable thickness are formed of fire-brick. The loaded trolleys are passed into one end of the kiln, which is a chamber 180 feet long, only slightly larger in section than a loaded truck. They emerge after three days, after having passed through a heat gradually increasing in intensity towards the centre of the kiln and then decreasing. Fuel is supplied through fire-holes in the roof of the kiln. The resultant are bricks more uniform in shape and colour than the ordinary hand-moulded brick, and, in addition, these are turned out at a much greater rate than by the hand process, and the manufacture can be carried on throughout the whole year. There is also great economy, as it is anticipated there will not be more than from 3 to 10 per cent. of grizzles or waste.

Kiln-Burnt Red Bricks, Hand-Moulded.—The processes through which this brick passes is as follows :—Clay getting, washing, weathering, pugging, moulding, drying, burning. All these processes but the burning are carried out as

previously described for malm or washed earth bricks. When the bricks are sufficiently dried they are burned in a kiln.

These kilns consist of four walls, without roofs. Fire-holes are arranged at the base, in which the coal for burning is added. These chambers are made sufficiently large to contain from 20,000 to 50,000 bricks. The bricks are stacked with a space between to allow the fire to permeate the mass. When the bricks are arranged the fires are applied gradually to drive off the moisture remaining in the bricks. This done, more fuel is applied, and the burning proceeded with. The top layer of bricks is protected by covering with old bricks to economize the heat. The bricks take from two to three days to burn, after which the fires are damped and the kilns allowed to cool gradually. Bricks burnt by this process are far more uniform in colour and regular in shape than clamp-burnt bricks. The best bricks are taken from the centre of the kiln; the bottom layers are liable to be fused; those at the top are generally underburnt, soft and unfit for face work. Kiln-burnt bricks may generally be classed as:—Builders' 1st, from middle of kiln. Builders' 2nd, from between 1st and 3rd. Builders' 3rd, bottoms and tops. The earth used is invariably a loamy clay containing a quantity of free silica, and generally the resultant colour is red.

Machine-Moulded Wire Cuts.—The operations to produce these bricks are as follows:—Clay getting, stone picking if necessary, grinding, or weathering and grinding, pugging, pressing, and squeezing through an orifice in a strip of about $4\frac{1}{2}$ inches by 9 inches section. It is then cut into 3-inch layers by means of wires arranged in a frame. The usual method of burning these bricks is in a Hoffmann or similar kiln. The Hoffmann kiln is circular in plan, and consists of an annular chamber divided by movable iron shutters into several compartments, usually 12, each of which is connected by a flue to a central chimney. The bricks, as

they are moulded, are stacked in one compartment of the kiln. When all the compartments are loaded the kiln is fired in No. 1 compartment, this being divided from the last compartment by an iron shutter. The flues in all the compartments, with the exception of the last, are closed. The heat consequently has to travel the whole circuit of the kiln, and through all the stacks of bricks igniting one after the other; the heat is thus gradually applied, thoroughly drying the bricks before burning. When the fire has passed on to about the sixth compartment, the first in which the bricks have been burnt is opened, and the bricks when sufficiently cooled are removed. This chamber is then refilled, the iron shutter closed between Nos. 1 and 2 compartments, the flue of No. 1 is opened, the iron shutter between last and first compartment is opened, and the flue in it is closed. No. 2 compartment is then opened, preparatory to emptying. The fire thus continues to travel in a cycle about the kiln.

Machine-Made Fletton Bricks.—Of late years large quantities of these bricks have been made in the neighbourhood of Peterborough, the output being at the rate of 8,000,000 per week.

The operations consist of clay getting, drying, grinding, sifting, pressing and burning.

The clay, which is obtained from the Oxford clay formation, is a dense bluish-grey shale, is dug, if necessary dried on a drying floor to expel superfluous moisture, ground in a mill similar to a mortar mill, the receiver revolving and carrying the clay under the rollers. The bottom of the receiver is perforated, which allows the material, when sufficiently ground, to fall through as a coarse powder into a pit beneath. It is then elevated and shot into a revolving circular inclined sieve; the material that is sufficiently fine passes through, the remainder is conveyed back to the grinding mill. The sifted powder falls into a hopper, from whence it is passed

to the pressing machine, where by an ingenious arrangement it is measured off and passed under the die, where it is pressed into the form of a brick, and removed automatically from the mould. The bricks are then placed on barrows and stacked in the kiln, which latter is of the Hoffmann type, and then burnt. The time of digging the clay to the stacking in the kiln need not occupy more than 15 minutes, the time taken to burn the bricks usually taking about three weeks. These bricks are of a good form, compact, and are useful for all internal work. Their colour, a reddish yellow, is not such as would fit them for the best facing work. For internal work to receive plaster, special bricks are prepared with dovetailed-shaped grooves.

RESULTS OF EXPERIMENTS ON SIX FLETTON BRICKS TO ASCERTAIN THE RESISTANCE TO A GRADUALLY INCREASED THRUSTING STRESS, OCTOBER, 1902.

Test No.	Description.	Dimensions.	Base Area.	Stress in Pounds, when		
				Cracked slightly.	Cracked generally.	Crushed.
		Inches.	Sq. ins.			
1	Light Red Brick, recessed one side.	2·64 × 8·74 × 4·18	36·53	89,700	151,200	155,000
2	Do.	2·65 × 8·70 × 4·13	35·93	82,200	134,200	134,200
3	Do.	2·62 × 8·72 × 4·16	36·27	83,400	120,500	133,100
4	Do.	2·64 × 8·65 × 4·23	36·59	83,600	124,500	124,500
5	Do.	2·64 × 8·73 × 4·12	35·97	79,600	118,400	122,700
6	Do.	2·68 × 8·78 × 4·25	37·31	68,200	113,800	122,100
		Mean	36·43	81,117	127,100	131,933
		Lbs. per square inch		2,227	3,489	3,622
		Tons per square foot		143·2	224·4	232·9

Bedded between pieces of pine ⅜-inch thick. Recess filled with cement.

The average Fletton brick when immersed in water for 24 hours will absorb 20 per cent. of its weight of water.

The usual dimensions of Fletton bricks are $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{5}{8}''$, weigh about 5·6 lbs. each, or, say, $2\frac{1}{2}$ tons per 1,000, but there is unfortunately no standard, and many different sizes are made.

The composition of the "Knotts" clay from which Fletton bricks are made is more or less as follows :—

Silica	50 per cent.
Alumina	16 ,,
Ferric Oxide	7 ,,
Calcium Carbonate	10 ,,
Magnesia	1 ,,
Alkalies	3 ,,
Organic Matter	6 ,,
Water	7 ,,
	100 ,,

but varies with the locality and with the depth below the surface from which the clay is taken ; the carbonate of lime is chiefly due to fossils, the quantity of which is very variable.

Indications of Processes.—The following hints are useful in determining some of the processes which a finished brick has passed through.

Hand-Moulded.—Frog on one side ; and no great amount of finish in the form, and porous.

Wire Cuts.—No frogs ; wire marks on the beds ; regular in form and dense.

Pressed bricks.—These have some or all smooth faces, sharp and regular arrises, clean frog or frog on both sides, and trade marks in the frog. These bricks are very dense.

Clamp-Burnt.—Colour (of the bricks) is not uniform ; the traces of the breeze can be seen, especially if the bricks

are broken across, when also the internal colour will be noticed to be darker and the texture slightly vitreous.

Kiln-Burnt.—Light and dark stripes upon the sides caused by the bricks being arranged with intervals between them while burning, the exposed parts being burnt to a light colour, and where resting upon or against another brick to a dark colour. This may be remedied by stacking the bricks upon their front faces in contact while burning.

Colour.—The colour of bricks is affected :—

(*a*) By the chemical constituents of the brick-earth.

(*b*) By the sand which has been sprinkled upon the raw bricks before being burnt.

(*c*) By the degrees of heat to which a brick has been subjected during the process of burning.

(*a*) The colour is determined chiefly by the quantity of iron present in the clay.

Bricks manufactured from clay free from iron burn white, and such clays, containing but a small quantity of chalk, together with iron, give a cream colour.

With a small quantity of chalk, but additional iron, a red colour is produced, and an additional quantity of chalk gives a brown.

Clays possessing from 8 to 10 per cent. of iron give in burning a blue or almost black colour.

Bricks in burning are exposed to a great heat, and if the clay contain alkalies, and be burnt at a still higher temperature, a bluish-green is produced, as in the case of Staffordshire bricks, which, under ordinary circumstances, are red.

White bricks usually contain but the merest trace of iron.

Blue bricks are prepared from earth containing a large proportion of oxide of iron.

Black bricks are made from a similar clay to the blue

bricks, but in addition the earth contains a small quantity of manganese.

To obtain a clear bright-red brick the clay should be free from impurities, and contain a large quantity of oxide of iron, which, in burning at a moderate temperature, is converted into the red oxide.

Magnesia in the presence of iron makes the brick yellow.

In clamp-burnt bricks the sulphur contained in the ashes gives them a yellow or brimstone tint.

(*b*) The sand sprinkled upon the raw bricks before they are burnt is vitrified in burning, and this will to a great extent affect the surface colour, which is but skin deep.

(*c*) As a general rule, the greater the amount of heat to which a brick has been subjected in burning the darker the tint.

The varieties of bricks in common use in the neighbourhood of London include—

Stocks, Fletton, Wire Cuts, Gault, Red, Blue, Black, Paviors, Fire-bricks, Salt-glazed, Enamelled.

The first three have been previously described.

Gault Bricks.—These are made from a bluish clay interposed between the upper and the lower greensand. The composition of the Gault Clay varies. Although of a fairly uniform dark blue colour, it contains at times (comparatively speaking) large quantities of the hydrous oxide of iron; at others, a good deal of calcium carbonate is found in combination.

The bricks are all burnt in the kiln, in the former case into a deep red brick or tile of an inferior quality, in the latter, perforated, hard, white bricks are made.

These bricks require great care in burning, for if the calcination of the calcium carbonate takes place under such conditions that the lime is left in a caustic state, it will slack on exposure to the weather, or when moisture is applied to it.

Suffolk Bricks, called also *White Suffolks*.—These are Gault bricks, and are kiln burnt, being expressly made for facings, but they are expensive. The best can rarely be obtained in London, being sold in the locality of their manufacture. They have a disagreeable cold hue, rendered still more dull after a few years' wear in a smoky atmosphere. They are not as well burnt as those possessing a somewhat light pink or salmon tint.

Beart's Patent Bricks.—These are Gault bricks, made at Arlesey, near Hitchin on the G. N. Railway, and comprise the following, ranged according to price :—

(*a*) White Rubbers, which are hand-made, moulded, solid, and equal to the best Suffolks.

(*b*) No. 1, best selected, white facing, pierced brick, are of uniform colour, hard, well burnt, and extensively used for facings.

No. 2, red and pink blended, differing from No. 1 in colour only, and are in every way equal to the best made stock bricks.

Red Bricks.—These bricks are made from a loamy clay in which the sand contains a considerable quantity of iron. These bricks are used as facings. A class of these bricks, upon which special treatment of careful washing, weathering and tempering of the brick earth, and which contains an excess of sand above that usually employed, are termed cutters or rubbers. They can be easily cut to any required shape by means of a brick saw, and in consequence of their fine texture can be rubbed to sharp arrises, and are also suitable for carving. They are largely used for arches and decorative work. The "Fareham Reds," and those supplied by Messrs. Blanchard, of Bishop's Waltham, are noted bricks of this class; and also the well-known T.L.B. rubbers, made by Messrs. Lawrence & Co., Bracknell, which are supplied largely to the London market.

Blue bricks are made from clays containing about 7 to 10 per cent. of oxide of iron. Large quantities of these are made in Staffordshire from the clays in that district. They are either wire cut or pressed, of a very dark blue colour, highly vitrified, very hard, dense, and capable of resisting great pressures. The same clay, if less burnt, produces a red brick.

They are largely used for engineering works and for piers where great compressional resistance is required. Special bricks are pressed for coping, channels and paviors.

Black bricks are made from earths containing a large proportion of oxide of iron together with oxide of manganese and burnt at a high temperature, and are especially useful for polychromatic work.

Paviors.—The following are used for the purposes of paving: Hard stock paviors, Blue Staffords, Dutch clinkers, and Adamantine clinkers. The first two have already been mentioned.

Dutch Clinkers.—These are very small, kiln burnt at a high temperature, hard, are used for paving, and usually made 6″ × 3″ × 1″, are vitrified throughout, and sometimes warped.

Adamantine Clinkers.—These are bricks similar to the above, but harder, denser, and heavier. They are of a fine pink-white colour, and present a smooth surface. The edges are sometimes chamfered in order to give a firmer foothold when used for paving. They are made of numerous sections, such as kerbs, channels, etc., and of varying dimensions.

Fire Bricks.—These are so named on account of the resistance they offer when subjected to a very great heat, which resistance depends chiefly upon the relative quantities of silica, alumina, and oxide of iron present in the clay. They are yellow in colour, close in texture, and are

made to the dimensions of an ordinary brick. The loam of which they are made is of a yellow colour, rough to the touch, and contains a considerable quantity of sand. They are highly serviceable for furnaces and ovens. They are made in various parts of Wales and called "Welsh Lumps," at Newcastle, at Poole, at the Hurlford Works near Glasgow, and at Stourbridge. The latter place supplies the London market chiefly, but the material is dear. The Dinas Brick, manufactured by the Ynysmudw Company, near Swansea, is said to resist a heat greater than the Stourbridge brick.

Salt-glazed Bricks.—These bricks have a thin glaze on their exposed surface caused by throwing salt in the kiln fire during the process of burning. This is explained in the article on stoneware.

Enamelled Bricks.—These have a white, light yellow, or other coloured surface like that of china, this surface being produced by covering a partially-burnt brick with a thin coating of white or other enamel over the required surface, and then reburning the brick. This is known as biscuit ware. Enamelled bricks of various colours, including white, are now manufactured by enamelling the raw brick and fixing the tint in one burning. These are more durable than those made by the biscuit process, but the best bricks of this make are expensive, as many are spoilt in burning. These bricks are much used for the sake of cleanliness in lavatories, dairies, etc., and also to reflect light in contracted areas.

Opalite.—This is a vitreous compound made in thin sheets of $\frac{1}{8}''$ bare in thickness, the front presenting a highly glazed appearance, the back being covered with rough particles of the same material, burnt on to form a key. This material is made of varying dimensions, frequently of sizes of the external faces of bricks, to which they are attached by being

bedded on a plaster specially prepared by the patentees. It is prepared in various colours, and is extensively and successfully used at a much less cost for all purposes for which glazed bricks would be suitable.

Crystopal.—Crystopal is a vitreous opaque compound, manufactured in thin sheets about $\frac{1}{8}''$ in thickness, with a highly glazed surface, prepared in different colours, and similar in essentials to opalite, the chief difference being the key, which with this material consists of a mastic of an elastic nature; it is applied to surfaces of brick, stone, or concrete, which are rendered in cement to form a ground; also to wood surfaces, to which it is secured with a mastic. It is claimed for this material that it does not crack through the differences in expansion and contraction of the different materials, the elasticity of the mastic compensating for these differences.

Characteristics of, and Tests for good Bricks.—Regularity of shape, uniformity of size, rectangular faces—only one end and side need be smooth—of uniform texture, compact and free from flaws of every description. The quantity of water absorbed by a brick is a good test of its quality. When saturated they should not absorb more than about 15 per cent. of their own weight of water, they should absorb it reluctantly, and part with it freely at moderate temperatures.

They should be uniformly burnt, hard, and give a metallic ring when two are knocked together—a dull sound indicating a soft or shaky brick; should be of a good colour for their kind, sound when broken, tough or pasty in texture, not granular; should require repeated blows before breaking rather than one hard blow; should stand cartage and handling well.

Absorption.—Insufficiently burnt bricks absorb a large quantity of water, and are not durable.

The absorption of bricks varies from one-sixth to one-fifteenth of their weight.

	Size in inches.			Weight in lbs.	Weight required per square inch to crush Brick in tons.	Percentage of Water absorbed.
London Stock	$8\frac{3}{4}$	$4\frac{1}{4}$	$2\frac{3}{4}$	6·81	3·558	$10\frac{1}{2}$
Red Kiln	$8\frac{3}{4}$	$4\frac{1}{4}$	$2\frac{3}{4}$	7·0	·96	—
Fareham Reds	8·5	4·15	2·6	6·3	·72	—
,, Rubbers ...	10·9	4·8	2·9	8·8	·32	—
Burham Wire-cut ...	8·6	4·0	2·6	5·4	1·35	19·0
,, Pressed ...	8·75	4·2	2·7	6·1	1·23	19·5
Suffolk White	9·2	4·3	2·6	6·3	·47	—
Tipton Blue	9	$4\frac{1}{2}$	3	10	·39	—
Adamantine Clinker ...	6	$2\frac{1}{4}$	$1\frac{3}{4}$	2	—	—
Dutch Clinker	$6\frac{1}{4}$	3	$1\frac{1}{2}$	1·55	—	—
Wire-cut White Gault	9	4·33	2·72	6·3	1·35	19·0

Machinery.—In the manufacture of bricks, where a great quantity is required, and where there seems a possibility of a regular demand, machinery is largely employed.

By machinery they are produced more cheaply, less labour being required.

Machines used for tempering the clay are called Pug Mills. Grinding machines consist of a pair of horizontal rollers, for crushing small fragments remaining in the clay. If, in addition, the clay is forced through an orifice, and then cut by wire according to the dimensions required, they are known as wire-cutting machines.

Still more recently machines have been used for tempering, moulding and pressing into the required form at one operation; that is to say, that the raw clay is placed in the machine, and is taken from it as a pressed brick.

Bricks, after the hand-moulding process, are often placed in a hand-pressing machine, with the object of correcting the form, and producing smooth faces and sharp regular arrises.

Strength of Bricks.—Bricks are subjected in practice to compression, sometimes to transverse stress, but not to tension, except such as would be caused by wind pressure or other lateral forces.

CRUSHING STRENGTH OF BRICKS (UNWIN).

(*Single Bricks. Faces made smooth and parallel by plaster of Paris.*)

Description.	Dimensions.	Cracked at tons per sq. ft.	Crushed at tons per sq ft.	Colour.	Remarks.
London Stock, max.	9·2×4·3×2·8	—	185	—	Twelve from different localities.
,, ,, min.	8·8×4·0×2·5	84	89	Yellow	
,, ,, mean	9·0×4·2×2·6	—	121	—	
Aylesford, Common	8·9×4·4×2·7	48	183	Pink	
,, ,,	8·9×4·4×2·7	111	228	,,	
,, Pressed	9·1×4·3×2·7	71	141	Red	Frog.
Grantham, Wire-cut	9·2×4·2×3·2	—	83	,,	
Leicester, ,,	8·9×4·5×3·2	228	246	,,	
,, ,,	9·1×4·2×2·8	115	229	,,	
,, ,,	4·4×4·2×2·7	225	365	,,	Mean of 7 half-bricks.
Gault, Wire-cut, max.	8·9×4·3×3·0	119	198	White	
,, ,, min.	8·7×4·1×2·7	89	145	,,	
,, ,, mean	8·8×4·2×2·8	—	178	,,	
Arlesley White, max.	9·1×4·2×2·9	—	207	,,	
,, ,, min.	8·8×4·1×2·7	50	107	,,	
,, ,, mean	8·9×4·2×2·7	—	161	,,	
,, ,, Wire-cut	9·0×4·2×2·7	151	239	,,	
Coventry	4·5×4·4×3·0	—	256	Red	Half-brick.
Fletton	8·6×4·2×2·7	137	203	Pink	
,, ...	8·8×4·1×2·7	126	169	,,	
,, ...	8·6×4·2×2·7	199	239	,,	
Glazed Brick... ...	8·8×4·4×3·3	69	166	White	Frog.
,, ,, ...	8·9×4·4×2·9	166	174	,,	,,
Kentish Stock, max....	9·3×4·4×2·9	107	127	Yellow	
,, ,, min....	9·1×4·3×2·8	30	54	,,	
,, ,, mean	9·2×4·4×2·9	—	82	,,	
Staffordshire Blue, max.	9·0×4·5×3·2	763	807	Blue	Nineteen half-bricks.
Staffordshire Blue, min.	8·9×4·1×2·7	152	296	,,	
Staffordshire Blue, mean	9·0×4·2×2·9	—	564	,,	
Stourbridge	8·8×4·3×2·8	157	209	Yellow	

CRUSHING STRENGTH OF BRICKS—*continued.*

Description.	Dimensions	Cracked at tons per sq. ft.	Crushed at tons per sq. ft.	Colour.	Remarks.
Stourbridge	9·0×4·3×2·8	161	242	Yellow	
,, ...	9·0×4·3×2·7	—	300	,,	
Red Rubbers, max....	10·1×4·9×3·4	—	93	Red	
,, ,, min....	9·9×4·8×3·3	36	67	,,	
,, ,, mean	10·0×4·9×3·4	—	77	,,	
Red Rubbers, three in column, bedded in putty.	9·0×4·5×8·0	—	25	,,	
Terra-cotta Block ...	6 sq. ins.	—	168		
,, ,, ...	15 ,, ,,	—	139		
,, ,, ...	15 ,, ,,	—	267		
,, ,, ...	6 ,, ,,	—	104		

Strength of Columns of Brickwork.—With piers of brickwork having a height of less than twelve times their least thickness.

	Weight per ft. super at which crushing commences. Tons.
Bricks, hard stocks, best quality, set in Portland cement and sand, 1 to 1, three months old	40
Bricks, ordinary well burnt, London stocks, three months old	30
Bricks, hard stocks, Roman cement and sand, 1 to 1, three months old	28
Bricks, hard stocks, Lias lime and sand, 1 to 2, six months old	24
Bricks, hard stocks, grey chalk, lime and sand, 1 to 2, six months old	12

The factor of safety for a working load may then be taken as $\frac{1}{5}$ to $\frac{1}{10}$ of the above quantities.

Tests of Brick Piers by a Committee of the Institute of British Architects.—Under the direction of a committee a series of piers of large size were built of five varieties of brick with both lime and cement mortar. These piers were 6 feet in height and generally 18 inches square. The piers of Staffordshire blue bricks were $13\frac{1}{2}$ inches square. The cement mortar was mixed by measure, the proportions

being 1 cement to 4 washed river sand. The grey lime mortar was mixed in the proportion of 1 to 2.

Unfortunately the piers first built were not very well built or the mortar was not quite satisfactory. The piers of the second and third series were built under more careful inspection and were stronger. The following table gives the results. The ratio of strength of pier to strength of brick has been calculated for the third series.

CRUSHING STRENGTH IN TONS PER SQUARE FOOT.

Mortar.	Age months.	Stocks.	Gault.	Fletton.	Leicester Red.	Stafford. Blue.
Single brick ...	—	84	189	221	362	780
Sand pier ...	—	—	—	—	15	—
		FIRST SERIES.				
Lime	3½	10·4	21·9	—	30·7	74·3
,, ...	10	12·5	21·6	—	34·1	73·7
Cement ...	3½	14·9	17·8	—	58·5	72·8
,, ...	10	19·7	30·0	—	50·4	82·5
		SECOND SERIES.				
Lime	3½	18·3	—	—	—	—
Cement ...	3½	—	49·6	—	86·4	103·1
		THIRD SERIES.				
Lime	5	18·6	31·1	30·7	45·4	114·3
Cement ...	5	39·3	51·3	56·3	83·0	135·4

RATIO OF STRENGTH OF PIERS TO THAT OF SINGLE BRICKS.

		THIRD SERIES.				
Lime	5	·22	·16	·14	·13	·15
Cement ...	5	·47	·27	·25	·23	·17

The pier of Leicester red bricks, built dry with simply a layer of sand in the joints, carried 15 tons per square foot, or half as much as similar piers built with lime mortar tested after 3½ and 10 months old.

Ratios of Strength of Brick Piers and Single Bricks.—The strength of brick piers built in mortar is often difficult to obtain, but they may be approximately determined by

knowing the ratios of the strength of masses of brickwork to the strength of single bricks. Unwin, in "Testing of Materials on Construction," gives ratios deduced from the following tests:—

TESTS OF BRICKWORK BUILT IN MORTAR.

Dimension of Pier.	Composition of Mortar.	Age of Pier in months.	Ratio of strength of brickwork in mortar to single bricks.	Authority.
10″ × 10″ × 9·5″	1 of lime, 2 of sand ...	3	0·44	Dr. Böhme, Berlin.
,, ,, ,,	7 of lime, 1 cement, 16 sand	3	0·48	
,, ,, ,,	1 cement, 6 sand	3	0·55	
,, ,, ,,	1 cement, 3 sand	3	0·63	
8·6″ × 8·6″ × 22″ high.	1 lime, 2 sand	$2\frac{1}{2}$	0·121	Wright & Keele Toronto.
9″ × 9″ × 24″ high.	1 lime, 2 sand	$2\frac{1}{2}$	0·292	
8·6″ × 8·6″ × 24″ high.	1 Portland cement, 3 sand	$2\frac{1}{2}$	0·258	
9″ × 9″ × 24″	1 Portland cement, 3 sand	$2\frac{1}{2}$	0·684	
12″ × 12″ × $117\frac{5}{8}$″	1 lime, 3 sand	24	0·07	American Society of Civil Engineers, 1887—1888.
8″ × 8″ × 17″	1 lime, 3 sand	15	0·18	
16″ × 16″ × 121″	1 Portland cement, 2 sand	24	0·11	
12″ × 12″ × $23\frac{1}{2}$″	1 Portland cement, 2 sand	23	0·26	
18″ × 18″ × 72″	1 grey lime, 2 washed river sand.	5	0·13	Committee of the Institute of British Architects.
18″ × 18″ × 72″	1 grey lime, 2 washed river sand.	5	0·22	
$13\frac{1}{2}$″ × $13\frac{1}{2}$″ × 72″	1 cement, 4 washed river sand.	5	0·17	
18″ × 18″ × 72″	1 cement, 4 washed river sand.	5	0·47	

Tensile Strength of Bricks.—The tensile resistance is given by Professor Rankine as varying from 280 to 300 lbs. per square inch.

*The R.I.B.A. Standard Size of Bricks.**—"The following standard, agreed upon between the Institute and the Brick Makers' Association, and drafted in consultation with these bodies and representatives of the Institution of Civil Engineers, came into force on the 1st May, 1904.

"The Council recommend that members should insert this standard in the specifications under the title of 'The R.I.B.A. Standard Size of Bricks.'

* Extract from the R.I.B.A. Kalendar, 1905—1906.

"1. The length of the brick should be double the width, plus the thickness of one vertical joint.

"2. Brickwork should measure four courses of bricks, and four joints to a foot.

"Joints should be $\frac{1}{4}$ inch thick and an extra $\frac{1}{16}$, making $\frac{5}{16}$ for the bed joints to cover irregularities in the bricks. This gives a standard length of $9\frac{1}{4}$ inches centre to centre of joints.

"The bricks, laid dry, to be measured in the following manner:—

"A. Eight stretchers laid square end and splay end in contact in a straight line to measure 72 inches.

"B. Eight headers laid side to side, frog upwards, in a straight line to measure 35 inches.

"C. Eight bricks, the first brick frog downwards and then alternately frog to frog and back to back, to measure $21\frac{1}{2}$ inches.

"A margin of one inch less will be allowed as to A, and a half-inch less as to B and C.

"This is to apply to all classes of walling bricks, both machine- and hand- made."

TILES.

Definition.—Tiles are thin slabs of brick-earth, burnt in kilns used for covering roofs, paving, etc.

Preparation.—The clay is prepared in a similar manner to that of bricks, but all the operations are conducted with greater care, especially in separating all the stones, on account of the thickness required being so small.

Shape.—Tiles for covering roofs are made in many forms and patterns; two of the most generally known and used being the plain and pan tiles.

Plain Tile.—The plain tile is rectangular in shape, the dimensions being $10\frac{1}{2}'' \times 6\frac{1}{2}'' \times \frac{1}{2}''$ in thickness. These tiles are made with two holes, through which are driven oak pins hanging over laths, or nails through boarding for fixing purposes. The tiles are now often made with small projecting nibs on the top under-edge for hanging purposes; when hung on steep slopes or vertical faces, they are nailed in addition.

The tiles are made slightly rounded in their length, the concave surface being kept under, in order that the bottom edge may bite well on to the tile below.

Plain tiles are made in three widths—half tile, tile, and tile and half, the first being used as the end tile of every alternate course to break joint. In many cases where secret gutters are used, or in similar positions, there is a difficulty in fixing a half tile properly, tile and half tiles are substituted to ensure an efficient fixing.

Special tiles are made to cover hips and valleys, and also to cover vertical angles where walls are weather tiled. Ridge tiles are made either plain or to ornamental patterns, special pieces being moulded for stopped ends, hipped ends, and intersecting ridges, or ridges intersecting with slopes.

Pan Tiles.—Pan tiles are made of a flat S shape 14 in. $\times$ 9 in. $\times$ $\frac{1}{2}$ in.; they are originally moulded flat, being bent to shape afterwards; they have a projecting nib on the underside of the top edge, by which they are hung to the battens. The hips and ridges are covered with segmental tiles bedded in mortar. These tiles when laid have a lap of three inches over the head of the tile immediately below; they do not lie so close together, and for that reason have to be bedded in mortar. Pan tiles do not form such a good covering as the plain tiles, and should only be used for sheds and workshops.

Paving Tiles.—Paving tiles are usually thicker, varying from $\frac{1}{2}$ to 1 inch, some being made from a similar clay to that

for ordinary tile; others are mixed with various substances to colour them. These are made in 6″ × 6″ squares, hexagons, and other geometrical patterns.

Manufacture.—The tiles are manufactured in a similar manner to bricks, going through the processes of clay-getting, tempering, moulding, drying, after which they are beaten to correct their shape, and then baked in a kiln.

TERRA-COTTA.

Terra-cotta is a material made from a refractory brick-earth, carefully selected and prepared; it is usually moulded into blocks, and built to represent ashlar work, being made up to 18 inches in length. The size of blocks of terra-cotta should never be made to exceed 4 cubic feet; undoubtedly blocks the contents of which do not exceed 1 cubic foot are much to be preferred.

Composition.—The following shows the composition of a typical specimen of terra-cotta:—

Silica	75·2
Alumina	10·0
Sesquioxide of Iron	3·4
Calcium Oxide	1·2
Magnesium Oxide	trace
Alkalies and Alkaline Chlorides ...	·5
Water	5·9
Organic Matter	7·7

It will be seen by the large amount of silica and the small percentage of alkaline matter present that the clay will be refractory, the quantity of the latter being just sufficient to cause a vitrified skin or surface, to which the material owes its durable qualities. The quantities of oxide of iron present, varying from the above amount to 10 per cent., impart the shades of pink and red common to terra-cotta.

Manufacture.—The material is carefully ground, strained

and pugged, and, to avoid excessive shrinkage in drying, sand, ground glass, or pottery is sometimes added. The mixing must be conducted with great care in order to ensure uniformity throughout the mass.

The material is moulded, carefully dried, and then baked. The two latter operations must not be accomplished in a hurried manner, or the material will twist.

The terra-cotta blocks are not made solid, but are built up hollow, the thickness of the sides varying from 1 inch to 2 inches, and have diaphragms or partitions connecting the opposite sides for their support. By this arrangement great thicknesses of the material are avoided, the drying is facilitated, and the surfaces and the interior are more uniform, thereby avoiding fractures, which would otherwise ensue.

In moulding the blocks, the thickness of the sides should be made of the same material throughout, and not made in two layers, as has been done, to economize the fine clay by placing a thin layer in front and using a coarser and inferior material on the back; the unequal contraction causes the two layers to separate.

Colour.—The colour varies with the temperature at which the clay is baked, and with the percentage of oxide of iron present. Colour may be imparted by giving the clay a wash of ochre paint before baking. This is inferior, soon wears, and should not be resorted to.

Two-coloured work.—Usually the blocks of terra-cotta are of one tint, but of late years Messrs. Doulton have perfected a process by carefully selecting the earth in which blocks each of two colours may be produced.

Fixing.—Terra-cotta blocks, when built in walls or anywhere to withstand pressure, have their voids filled up with ordinary Portland cement concrete; this usually causes discoloration due to the cement concrete working through. A filling composed of Portland cement and ground terra-cotta

is more effective. The voids are left hollow in floors or any position where lightness is desirable.

Moulded work in terra-cotta, owing to the unequal shrinkage in drying, often becomes slightly twisted, which in buildings with a long run of cornice or string mouldings has a bad effect. This is often corrected by chiselling parts of the face; but it should not be allowed, as, if the vitrified surface skin be destroyed, the remainder will rapidly disintegrate under the influence of the weather.

The dimensions of the blocks are usually some multiple of brick dimensions, in order to bond with the brick backing.

Terra-cotta is most suitable for decorated panels, statuary, and work which would have to be carved if in stone, especially where these have to be reproduced several times.

STONEWARE.

Stoneware is prepared from clays of the Lias formation, consisting of silica and alumina, with a small percentage of iron, calcium, etc.

The clay is prepared in a similar manner to the brick-earth, usually being mixed with a proportion of ground stoneware or sand to avoid excessive contraction in burning.

The articles are moulded by various processes, and burnt in a domed kiln; the material is practically non-absorbent, but to ensure this the articles are glazed.

The glazing is performed by adding sodium chloride when in the kiln, which is volatilized by the heat, and in the form of a vapour is decomposed by the silicates of alumina, with which it combines to form a glass, the chlorine passing off from the kiln.

The sodium chloride in the form of a vapour penetrates into all the pores of the stoneware, completely covering the surface with a coating of glass.

This material is chiefly used for such articles as drain and sewer pipes, damp-proof courses, or any position where

a damp-resisting material is required. These articles are burnt in kilns at a very high temperature, and when finished are thoroughly vitrified throughout their whole thickness.

IRON AND STEEL.

Ores.—Iron is extracted from ores of which the following are the most abundant:—

Magnetic Iron Ore, or "Magnetite," a black oxide, when pure, yields 72·41 per cent. of metallic iron, the formula being Fe_3O_4. Swedish iron is obtained from this ore. It is very valuable, and is found in considerable quantities in many parts of Europe, America, and Asia.

Red Hæmatite is an oxide of iron containing 69·5 per cent. of iron, and is valuable as an iron-producing ore. Its formula is Fe_2O_3.

Brown Hæmatite is a hydrated peroxide of iron. Its formula is $2Fe_2O_3 + 3H_2O$. It yields about 59·89 per cent. of metallic iron.

Spathic Iron Ores, Clay, or Cleveland Ironstone are names given to ferrous carbonate ores, $FeCO_3$, from which nearly two-thirds of the total weight of pig iron produced in Great Britain are smelted. The purer ores are known as spathic, whilst the amorphous argillaceous ores of the coal measures are known as clay ironstones, and when largely impregnated with carbonaceous or bituminous matter are called blackband ironstone. The spathic ore when pure yields about 48·27 per cent. of metallic iron.

Iron Pyrites is a bisulphide of iron (FeS_2), containing as much as 40 per cent. of sulphur, and is unfit for the extraction of iron.

The foregoing ores are more or less found in combination with impurities, such as manganese, magnesia, silica, alumina, lime, carbon, sulphur, and phosphorus, and seldom yield more than 33 to 66 per cent. of metallic iron.

Cast Iron.

Production.—(*a*) The mechanical preparation of the iron ore, such as breaking up with the hammer, crushing and washing.

(*b*) The weathering of the ore; that is, leaving the ore in the open, exposed to the effects of the winter. This is not applicable to calcareous ores.

(*c*) Roasting or calcination to expel the water, CO_2, and other matters. This is generally accomplished by mixing the ore and fuel together, and setting fire to the mass.

(*d*) Smelting in the blast furnace. Fluxes in iron-smelting are used to combine with the earthy parts of the iron ore, and thus the pure iron is liberated. Limestone, clay, and sometimes sand is used as a flux. Charcoal and coke are principally used as fuel. Iron ores are frequently mixed together in the blast furnace, in order that the earthy matters of the different ores may act as fluxes without the addition of other materials.

Air is forced into the furnace by means of a blowing engine. In the older types of furnaces the air was not heated, and this was said to be a cold blast; but in the modern examples, the gases which previously were allowed to escape are utilized to heat the air, which is then forced into the furnace at heats varying from 500° to 700° Fahr.; it is then termed the hot blast. Coke or charcoal are the only fuels employed in the cold blast, but the hot blast admits of the use of coal. It is generally acknowledged that the hot blast may, with proper care, produce as good an iron as the cold blast; but the heat obtained in the former method is so great that it is possible to reduce refractory cinders and slags, therefore successful working requires skilful manipulation.

(*e*) Pig Iron is the production of the blast furnace. It consists of a combination of pure iron with carbon, both in

chemical combination and mechanically mixed. Other substances, such as silicon, sulphur, phosphorus, and manganese, are found in pig iron. The pigs are often divided into six varieties. Nos. 1, 2, 3 are termed foundry pigs, and are used for the production of grey cast iron; they are less fusible, but more fluid when molten than the whiter varieties, and have the property of expanding a little at the moment of solidification. Nos. 4, 5, 6 are described as forge pigs; they are stronger and more brittle than the grey, and are used for conversion into wrought or pure iron.

(*f*) *Grey Cast Iron.*—This class of cast iron has the greatest ratio of uncombined or graphite carbon, and but a very small quantity of chemically combined carbon, viz., 2·9 to 3·7 per cent. crystallizes separately as graphite, and ·6 to 1·5 chemically combined.

(*g*) *Mottled Cast Iron* (No. 4 pig) has a larger proportion of the chemically combined carbon, and is stronger, whiter, and more lustrous than the grey varieties, has a granular and more or less mottled appearance on fracture, and is used only for the heaviest classes of foundry work, and is unsuitable for light or ornamental castings.

(*h*) *White Cast Iron* has nearly all its carbon in chemical combination. The quantity varies from 3 to 5 per cent.

(*i*) *Pig Irons* of various qualities are mixed together in the foundry cupola furnace to produce iron suitable for particular kinds of castings. All castings are usually specified to be of the second melting, but it has been proved by experiment to be better up to the twelfth remelting.

Characteristics.—Cast iron may be described as hard, brittle, fusible at 2,000° Fahr., a temperature easily obtainable in the blast furnace; but is not forgeable nor weldable.

Tests.—Cast iron bars 1 inch square in section, and laid upon supports 1 foot apart, should resist a load of 1 ton placed in the centre of its length. The sound should be noted, and

a close examination made to discover if any flaws or air bubbles exist. Chemical tests are of very little use, as indications of the quality must depend upon practical knowledge.

Dilute nitric acid applied to a clean fracture of grey iron will produce a black stain, and to a white iron a brown stain.

Uses.—Grey Cast Iron is mostly used in construction for columns, stanchions, short struts, and generally to resist compression, but is not suited to withstand tensile stresses.

Specifications for Constructional Cast Iron.—1. Except where chilled iron is specified, all castings shall be tough grey iron, free from injurious cold shuts or blow holes, true to pattern and of a workmanlike finish. Sample pieces 1 inch square cast from the same heat of metal in sand moulds shall be capable of sustaining on a clear span of 4 feet 6 inches a central load of 500 pounds when tested in the rough bar.

Wrought Iron.

The Production of Wrought Iron.—Wrought Iron is nearly the pure metal, containing usually not more than 0·15 per cent. of carbon.

(*a*) Refining consists in keeping the pig iron in a state of fusion on an open hearth with coke or charcoal while a blast of atmospheric air from several inclined twyers is at the same time directed upon the surface of the molten metal. It is an operation having for its object the decarburization and purification of pig iron, which it only partially accomplishes, and produces fine or plate metal, and before conversion into malleable iron must be puddled. This process is now rarely employed.

(*b*) Puddling, or Pig Boiling in the puddler's reverberatory furnace, sufficiently removes the carbon and the impurities, producing puddled balls. Dry puddling is the name given to the process when refined iron is employed, and pig boiling when raw or pig iron is used direct. The extent to which

most of the foreign substances are removed from the pig iron by puddling may be inferred from the comparison of the composition of a puddled bar with that of the good No. 3 grey cold blast Staffordshire pig, from which it was obtained :—

	Pig Iron.	Puddle Bar.
Carbon	2·28 ...	0·30
Silicon	2·72 ...	0·12
Phosphorus	0·65 ...	0·14
Sulphur	0·30 ...	0·13
Iron...	94·05 ...	99·31

(*c*) Shingling, or Blooming, or crushing with the steam hammer, to force out the cinder, and consolidate and weld the particles of iron together, and rolling to produce puddle bar.

(*d*) No. 1, Rough or Puddled Bar Iron, is coarse and brittle, of a low tensile strength, usually employed in the production of better qualities of iron.

(*e*) No. 2, or Merchant Bar Iron, also known as common iron, is the lowest quality used by the smiths; it is hard and brittle, and only fit for rough work, is produced by piling up puddled bars, raising them to a welding heat, and passing them through rollers.

(*f*) No. 3, B or Best Iron, is produced from No. 2 by the process of piling, reheating, and rolling. This quality is used for ordinary good work.

(*g*) BB Iron is produced from No. 3 by a similar process of piling, reheating, and rolling; this quality, and also BBB Iron, is used for special purposes.

Rolling.—The particles of wrought iron after reheating or exposure to a high temperature assume or revert to a crystalline state of a cubical form. Hot rolling converts these crystals into fibres, nearly doubles the tensile strength, but reduces the ductility of the metal. After the fifth reheating, the iron loses instead of gaining in tensile strength. Cold rolling puts a polish on the outside surface of the

metal, making it harder than the interior; in all other respects it has a similar effect upon the iron as mentioned for hot rolling.

Characteristics.—Wrought or Pure Iron may be described as soft, malleable, ductile, weldable at white heat (at 1,500° to 1,600° Fahr. it softens and can be welded), easily forgeable, very tenacious, but not fusible except at high temperatures, viz., 3,000° Fahr., and is not temperable.

Tests of Resilience.—The quality is usually decided by noting its strength and ductility by taking specimens about 10 inches in length and subjecting them to tension in a testing machine. The standard required for constructional purposes is that it should elongate 20 per cent. of its length under a slowly applied tensile-breaking stress; thus, a specimen, 1 inch in sectional area and 10 inches in length should measure 12 inches in length at time of rupture, and fail under a gradually increasing stress of not less than 22 tons per square inch. The value of the resilience will thus be equal to 22 inch tons, being the given average resistance multiplied by the increase of length.

Sometimes the iron is specified to be bent through a given angle without cracking, sometimes hot and sometimes cold; the better the iron the more it can be bent, and the test is more severe when the operation has to be performed cold. Thus, rivet iron is specified to be bent double when cold without cracking.

Dilute nitric acid applied to a clean fracture will leave a greenish stain.

Uses.—Wrought iron is of a fibrous nature, and is therefore very suitable to resist tensile stresses, and has been much used for roofs, girders, and long stanchions. For the latter purpose, the reliable nature of the material is a great recommendation, but it is now being displaced by mild steel,

Steel.

Definition.—All combinations of iron and carbon which are malleable and permit of being hardened and tempered, and capable of being cast into a malleable ingot, may be considered as steel.

Classification.—Steel may be divided under two heads: mild or soft, and hard. Mild steels include shear, double shear, and those made by the Bessemer and Siemens processes. These may be employed for all constructional purposes, but the expense of shear and double shear generally precludes their use, so the Bessemer and Siemens are now almost universally employed for work where great strength, tenacity, and ductility are required without any very great hardness. Hard steel includes the crucible cast, especially useful for cutting tools, and the Whitworth compressed ingot, which, being compressed in the liquid state with a hydraulic force varying from 10 to 20 tons per square inch, reduces the number of small gas cells to which ordinary cast steel is usually subject.

Production.—There are three distinct systems adopted in the manufacture of mild steel.

First, the cementation process, viz., that of refining cast iron into an almost pure wrought iron, and then afterwards combining the pure wrought iron with a definite amount of carbon, the CO_2 from the charcoal and oxygen being absorbed, and thus giving to iron the nature of steel.

Bars of wrought iron embedded in charcoal are exposed to white heat (2,142° Fahr.) in a cementation furnace; the time occupied by the process depends upon the quality of the steel required—it generally requires from one week to a fortnight. The converted bars are classed as blistered steel. From this quality by a repetition of the three processes piling, reheating, and welding, are produced single shear steel, and double shear steel.

Spring Steel is blistered steel heated to an orange-red colour and hammered or rolled.

Single Shear, or Tilted Steel, is produced from bars of blistered steel, piled into bundles, placed at a welding heat under the tilt hammer, which removes the blisters, closes the seams, and forms one bar of single shear steel. The process is again performed upon single shear to produce double shear steel.

Crucible Cast Steel is made by melting blister steel in covered fire-clay vessels, and running the metal into iron moulds. In another method, Swedish wrought-iron bars of good iron are melted into the vessel with charcoal.

Secondly, the process introduced by Sir Henry Bessemer, in which a volume of dense air is forced through the crude cast iron in the molten state. During its passage the oxygen combines chemically with the carbon, and carbon dioxide passes off, thus leaving the iron comparatively pure. In order to make it into steel there is added to the purified metal a measured portion of pure cast iron, commonly called "Spiegeleisen," or "looking-glass iron." An analysis of one sample of this contained 82·86 iron, 10·71 manganese, 1·0 silicon, 4·32 carbon—total 98·89 parts. It is introduced in the melted state in the proportion of 1 part to 30 parts of the pig iron employed. The vessel employed for the fusion of the molten ores is called a converter, and is often made capable of containing 6 to 10 tons of material. The operation takes about twenty minutes. This steel is produced at a much less cost than by the cementation process.

Thirdly, the Siemens, or open hearth process, consists in mixing and heating an iron ore, rich in oxide, with the mass of crude iron, and sometimes steel scrap. In this, the oxygen of the ore and the lining performs the same chemical office as that from the air in the Bessemer process, and, uniting with the carbon in the crude iron, passes off as carbon dioxide. The lining, siliceous or basic, is made good

each time. By means of this system manufacturers are enabled to produce steel of any degree of softness, suitable for constructional work generally. The best steel for high-class cutlery and tools is produced by the cementation process. The Bessemer turns well, but the time taken in the Siemens process allows tests to be made, and a more uniform quality is ensured. The Bessemer steel is slightly cheaper than that produced by the Siemens process.

Processes.—Both the Bessemer and Siemens processes are divisible into two classes: first, that conducted in acid (siliceous) lined vessels or furnaces in which only the purer kinds of pig iron can be operated upon; and the second, in similar vessels or furnaces, but with basic (dolomitic) linings, which are capable of using the more impure phosphoric pig irons. In the Bessemer process the acid lining serves for about 220 charges; the basic lining for a lesser number.

Characteristics.—Steel may be described as highly elastic, malleable, ductile, forgeable, weldable, capable of receiving different degrees of hardness by tempering, and fusible at a lower temperature than wrought iron (at 2,400° Fahr.); hardened steel is noted for its property of retaining magnetism. Generally speaking, the smaller the amount of carbon steel contains, the nearer will its properties resemble those of wrought iron; the greater the quantity it possesses tends to make its characteristics similar to cast iron. In the softer or milder steels the structure approaches more closely to a fibrous condition. In the harder varieties the structure shows it to be fine, shining, and uniformly granular, the grains being in lines perpendicular to the sides of the ingot.

Tests.—Steel should be tested for strength and ductility, which is known as the resilience test; thus a mild steel suitable for construction should possess an ultimate resistance under a slowly applied tensile stress of 30 tons per square inch, and the metal should elongate 20 per cent. of its length

before fracture takes place. Thus, a bar of 1 inch sectional area and 10 inches long will stretch to 12 inches before rupture, a gradually increasing force up to 30 tons being required to cause the same. The sound should also be noted, and sometimes a forged test is required, viz., to bend hot or cold, with or across the grain, without fracture, through angles varying 20° to 90°. Dilute nitric acid applied to a clean fracture of steel will leave a dark grey stain, owing to the separation of carbon.

Patterns.—A smaller allowance for shrinkage is required in patterns for steel castings than for cast iron.

Uses.—Mild steel is suitable for constructional purposes generally, members for bridges, girders, roofs, etc., and has practically displaced the use of wrought iron for constructional purposes. Hard cast steel is used for cutting tools.

Hardening and Tempering.—These are distinctive properties of steel. Mild steel, containing from ·2 to ·5 per cent. of carbon, will weld, but does not temper, and will elongate from 25 to 30 per cent. of its length before fracture under a tensile breaking stress of 25 to 30 tons per square inch. When the carbon reaches 1·5 to 2 per cent., it is at the expense of tenacity and weldability of the material; but these harder varieties are better suited for the process of tempering. Hardening lowers the specific gravity, but increases the tenacity.

Smithing.—The smithing of steel is more difficult than that of wrought iron, and it is more liable to injury from over-heating, therefore necessitating greater care.

Punching. — Steel plates sustain greater injury when punched than wrought iron. Occasionally in punching, a fracture is produced, extending to the edge of the plate. Experiments made show that the loss of strength of plates with drilled holes is less than that of similar plates punched; if punched, steel plates should be annealed, when the greater

part of their strength is restored; but to resist a shearing stress, drilled holes are 4 per cent. weaker than those punched.

The usual practice with steel plates is to punch those with a thickness of less than $\frac{1}{2}$ inch, and not to anneal them afterwards. Plates $\frac{1}{2}$ inch to $\frac{3}{4}$ inch in thickness are punched, and rymered or annealed afterwards; plates more than $\frac{3}{4}$ inch should be drilled. The tendency of modern practice is now to drill all plates.

Fracture.—Cast iron may be described as crystalline, wrought iron as fibrous, and steel as of a granular nature. If a breaking stress be applied slowly, the fractures upon the representative specimens of each class will be: Cast iron, crystalline; wrought iron, fibrous; and steel, silky fibrous; but if a breaking stress is suddenly applied, it will tend to cause all the fractured specimens to be crystalline; thus, cast iron will be very crystalline, wrought iron less crystalline, and sometimes fibrous threads will be interwoven, and steel invariably granular.

Sound.—Cast iron, when struck, will give comparatively a hollow sound; wrought iron, a note of a low pitch; but steel will give a distinctly clear treble ring.

Phosphorus is largely taken up by iron during the process of smelting. Its effect upon cast iron is to harden it, to render it more fusible, but to reduce its tenacity. Wrought iron, with $\frac{1}{10}$ per cent. of phosphorus, is better for welding. Half per cent. makes the metal cold short; that is, brittle at low temperature, and cracking when bent. Antimony and tin will have a similar effect. Steel is injured by the presence of phosphorus even in the smallest quantities.

Sulphur in cast iron tends to produce the mottled and white varieties; in wrought iron $\frac{3}{10}$ to $\frac{4}{10}$ per cent. produces red or hot shortness, that is, causes the metal to be brittle at high temperatures. In steel, $\frac{2}{10}$ per cent. renders

it unfit for forging, but makes it more fluid and better for casting. One-tenth per cent. produces red shortness.

Manganese is nearly always present in cast iron. It tends to produce the white variety, in which a large proportion is generally found. In wrought iron and steel it counteracts red shortness, most probably by encouraging the departure of sulphur and silicon, and is essential in the manufacture of Bessemer and Siemens steel.

Copper in cast iron to the extent of $\frac{2}{10}$ per cent. does no harm. In wrought iron $\frac{1}{2}$ per cent. makes it red short. In steel $\frac{1}{2}$ per cent. makes it red short. Two per cent. causes it to be brittle.

Case-Hardening.—Wrought iron may have its outer crust partially converted into steel by either of the following processes, when it is said to be case-hardened :—The surface of the iron is made bright; it is then placed in a very clear fire until red-hot, then rubbed with powdered yellow prussiate of potash, and then reheated until the iron assumes a cherry-red heat, when it is cooled suddenly by being immersed in water. It is more effectually case-hardened by placing the bright iron in a close iron box filled with bone dust and cuttings of horn and leather substances, which part with their carbon (sometimes common salt is added), and heating for twenty-four hours in a fire. This method is employed in small parts, such as pins, where the wearing property of steel is desired to be combined with the ductility of wrought iron.

Malleable Iron.—Small articles of cast iron are sometimes made partially or wholly malleable by surrounding the casting with an oxidizing compound, such as oxide of iron or powdered red hæmatite, and keeping it at a high temperature for a time ranging from two to forty hours, varying with the size of the casting, to eliminate the carbon and convert it into a material resembling wrought iron. Decorative parts of ironwork to withstand blows are often treated

in this manner. Castings of $\frac{1}{2}$ inch in thickness are rendered malleable throughout; thicker castings have only the skin rendered malleable.

Preservation of Iron.—Cast iron should be painted soon after it leaves the mould to preserve intact the hard skin before it has time to rust. Lead paints are often used, but as galvanic action is set up, oxide of iron paints should be preferred. Cast-iron pipes are effectually treated by Dr. Angus Smith's process, which consists in cleaning the castings and heating them to 700° Fahr., and dipping them in a mixture heated to 300°, consisting of coal tar, pitch, 5 per cent. of linseed oil, and a little resin.

Wrought-iron sheets are effectively protected by being galvanized, which consists in cleaning the iron with sulphuric acid, scouring with sand, and washing until clean with water, and then covering the iron with a thin coating of zinc. Wrought iron and steel are preserved by the process of superheated steam (Barff's process) and superheated air (Bower's process), which latter is much cheaper for cast iron. These processes cover the iron with a coating of black magnetic oxide, Fe_3O_4 with more or less Fe_2O_3 and some Fe_4O_5, which effectually resists oxidation from damp earth, salt water, and other causes.

Steel.—The usual method to preserve steel is to cover the same with paint.

Ironwork rusting after being painted can be distinctly seen, and this is considered a great advantage in favour of this treatment.

Factors of Safety.—Rankine gives the following as a fair summary of our knowledge respecting factors of safety:—

Good materials and ordinary workmanship.

	Dead Load.	Live Load.
Metals...	3	6
Timber	4 to 5	8 to 10
Masonry	4	8

	Specific Gravity.	Weight per ft. cube in lbs.	Ultimate strength in tons per square inch.			Safe working loads in tons per square inch for dead load.			Modulus of Elasticity. Lbs. per square inch.	Limit of Elasticity.	Chemical Analysis.
			Compression.	Tension.	Shearing.	Compression.	Tension.	Shearing.			
Cast Iron	7·2	450	40 to 45	7 to 8	12	8 to 9	$1\frac{1}{2}$ to $1\frac{3}{4}$	2	18,000,000	$\frac{1}{3}$ of ultimate strength	Contains 3 to 5 per cent. of carbon
Wrght. Iron	7·6	480	16 to 17	20 plates 25 bars	22	4	5	4	25,000,000 to 29,000,000	$\frac{1}{2}$ of ultimate strength	Not more than ·15 chemically combined carbon
Steel, Mild	7·8	490	22 to 35, 30 usually employed	25 to 30, 30 usually employed	24	6	6	5	30,000,000	·45 to ·8 of ultimate strength	·15 to 2 per cent. of chemically combined carbon

The Board of Trade limits the greatest stress in the flanges of wrought-iron girders to 5 tons per square inch on either section, and in the flanges of steel girders $6\frac{1}{2}$ tons per square inch.

It is usual not to let the working load upon a long pillar exceed one-tenth of its ultimate resistance.

Oxidation.—The comparative oxidation or rusting of cast iron, wrought iron, and steel in moist air (ordinary rust of iron $2Fe_2O_3$, $3H_2O$), are respectively as 100, 129, 133. Cast iron is, therefore, the best of these materials to resist oxidation.

BRITISH STANDARD SPECIFICATION FOR STRUCTURAL STEEL FOR BRIDGES AND GENERAL BUILDING CONSTRUCTION.*

1. *Process of Manufacture.*—All plates and rivet bars shall be made by the open hearth process, acid or basic, as may be approved in writing by the engineer (or by the purchaser), and must not show on analysis more than ·06 per cent. of sulphur or of phosphorus.

Sectional material for bridges shall be made by the open hearth process, acid or basic, as may be approved in writing by the engineer (or by the purchaser), and must not show on analysis more than ·06 per cent. of sulphur or of phosphorus.

Sectional material for general building construction shall be made by the open hearth or Bessemer process, acid or basic, as may be approved in writing by the engineer (or by the purchaser), and must not show on analysis more than ·06 per cent. of sulphur, nor ·07 per cent. of phosphorus.

The maker shall supply an analysis of each cast when required to do so. Samples may also from time to time be

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subject to complete analysis by a metallurgist appointed by the engineer (or by the purchaser), and at his expense.

2. *Freedom from Defects.*—The plates, sections, and bars must be free from cracks, surface flaws, laminations, and all other defects, and finished in a workmanlike manner. No plate or section must be more than $2\frac{1}{2}$ per cent. over, or $2\frac{1}{2}$ per cent. under, the calculated weight.

3. *Mechanical Tests.*—The tensile strength and ductility shall be determined from standard test pieces cut lengthwise or crosswise from the rolled material in the case of plates, and lengthwise in the case of sectional material and bars. When material is annealed or otherwise treated before despatch, the test pieces shall be similarly and simultaneously treated with the material before testing.

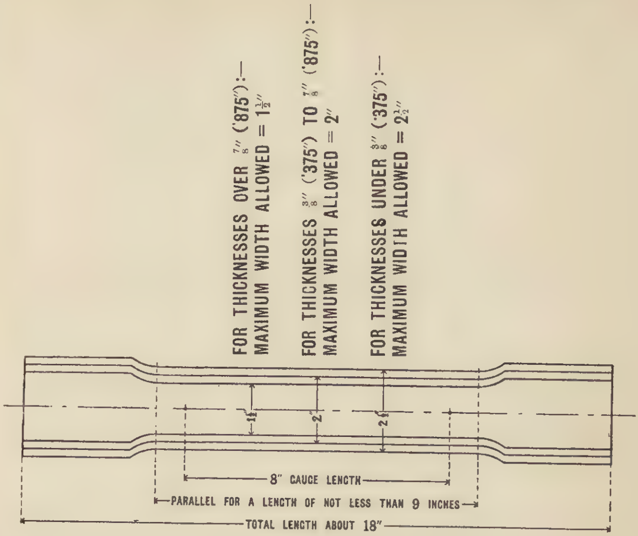
Any straightening of test pieces which may be required shall be done cold.

4. *Selection of Test Pieces.*—Plates, sectional material, and rivet bars must comply with the following mechanical tests, which shall be made at the steel maker's works prior to despatch. Except as provided for in clause 13, all test pieces shall be selected by the representative of the engineer (or of the purchaser) and tested in his presence; he shall satisfy himself that the conditions herein prescribed are fulfilled, and no plates, sections, or bars shall be forwarded from the steel works until the prescribed tests have been made by the representative of the engineer (or of the purchaser), and the mill sheets signed by him.

5. *Tensile Tests.*—Plates and Sectional Material:—For plates, angles, &c., a standard test piece having a gauge length of 8 inches (test piece A, see page 131), and for round bars (other than rivet bars) a standard test piece having a gauge length of not less than 8 times the diameter (test piece B, see page 131), must show a tensile breaking

TEST PIECE A.

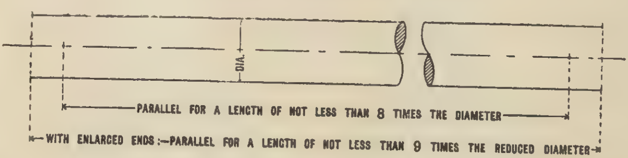
FOR PLATES AND OTHER STRUCTURAL MATERIAL.



NOTE:—It will be observed that the widths given above, being maxima, do not exclude the use of the usual $1\frac{1}{2}$ in. × 8 in. test piece.

TEST PIECE B.

FOR BARS, RODS, AND STAYS.



Bars, Rods, and Stays may be tested either full size as rolled, or turned down when the diameter is considerable. In both cases the gauge length on which the extension is measured shall not be less than 8 times the diameter of the test piece, and where enlarged ends are used the parallel portion shall not be less than 9 times the diameter of the test piece.

strength of 28 to 32 tons per square inch, with an elongation of not less than 20 per cent. For material under $\frac{5}{16}$ of an inch (·312 inch) in thickness bend tests only are required.

Rivet Bars :—A standard test piece having a gauge length of not less than 8 times the diameter (test piece B, see page 131), must show a tensile breaking strength of 26 to 30 tons per square inch, with an elongation of not less than 25 per cent. The bars may be tested the full size as rolled.

6. *Number of Tensile Tests.*—One tensile test shall be made from every cast or every 25 tons, whichever is least.

Should a tensile test piece break outside the middle half of its gauge length, the test may, at the maker's option, be discarded and another test be made of the same plate, section, or bar.

7. *Bend Tests.*—Cold Bends : — Test pieces shall be sheared or cut lengthwise or crosswise from plates or lengthwise from sectional material, and shall be not less than $1\frac{1}{2}$ inches wide, but for small sections or bars the whole section may be used.

Temper Bends :—The test pieces shall be similar to those used for cold bend tests. For temper bend tests the samples shall be heated to a blood red and quenched in water at a temperature not exceeding 80 degrees Fahr. The colour shall be judged indoors in the shade.

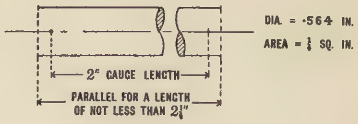
In all cold or temper bend tests, the sheared edges may be removed by milling, planing, grinding, or other method. The test pieces shall not be annealed unless the material from which they are cut is similarly annealed, in which case the test pieces shall be similarly and simultaneously treated with the material before testing.

For both cold and temper bend tests the test piece must withstand, without fracture, being doubled over until the

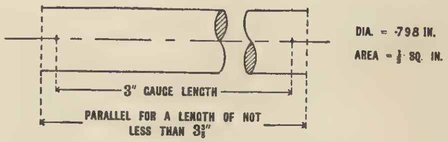
TEST PIECES C AND D.

FOR TYRES, AXLES, FORGINGS, CASTINGS, ETC.

TEST PIECE C.



TEST PIECE D.

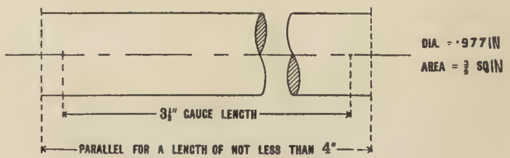


The gauge length and the parallel portion are to be as shown. The form of the ends is left open in order to suit the various methods employed for gripping the test piece.

TEST PIECE E.

The following test piece may be used when a test piece is required similar in form to C and D, but of larger dimensions.

TEST PIECE E.



internal radius is not greater than $1\frac{1}{2}$ times the thickness of the test piece, and the sides are parallel.

Bend tests may be made by pressure or by blows.

For rivet bars bend tests are not required.

8. *Number of Bend Tests.*—One cold or one temper bend test shall be made from each plate, section, or bar as rolled.

9. *Additional Tests before Rejection.*—Should the test pieces first selected by the representative of the engineer (or of the purchaser) not fulfil the test requirements, two further tests may be made; but should either of these fail, the plates or sectional material from which the test pieces were cut shall be rejected. In all such cases further tests shall be made before any material from the same cast can be accepted.

10. *Tests for Manufactured Rivets.*—Manufactured rivets selected by the representative of the engineer (or of the

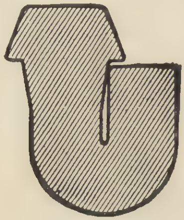


Fig. A.

Fig. B.

purchaser) from the bulk, in such proportion as may be specified and approved, must withstand the following tests:—

(*a*) The rivet shanks shall be bent cold, and hammered until the two parts of the shank touch in the manner shown in Fig. A, without fracture on the outside of the bend.

(*b*) The rivet heads shall be flattened, while hot, in the manner shown in Fig. B, without cracking at the edges. The head shall be flattened until its diameter is $2\frac{1}{2}$ times the diameter of the shank.

11. *Branding.*—All plates and sectional material shall be legibly marked in two places with the maker's name or trade mark, the place where made, and with number or identification marks by which they can be traced to the cast from which the material was made. For small pieces securely bundled, a metal tag marked with the cast number will be sufficient.

12. *Facilities for Inspection.*—The maker shall adopt a system of marking the ingots, billets, slabs, plates, sectional material, &c., which will enable all finished material to be traced to the original cast; and the representative of the engineer (or of the purchaser) shall be given every facility for tracing all plates and sectional material to their respective cast, and for witnessing the required tests.

13. *Certificate in lieu of Inspection.*—In cases where no inspection takes place at the works the maker shall supply to the purchaser a signed test sheet giving the results of the mechanical tests made on the product of each cast, and, when required, of the analysis. Such test sheet shall indicate the numbers or identification marks of the casts to which it applies, which numbers shall be found on each piece, plate, or section.

14. *Inspection.*—The representative of the engineer (or of the purchaser) shall have free access to the works of the maker at all reasonable times; he shall be at liberty to inspect the manufacture at any stage, and to reject any material that does not conform to the terms of this specification.

15. *Testing Facilities.*—The maker shall supply the material required for testing free of charge, and shall, at his own cost, furnish and prepare the necessary test pieces, and supply labour and appliances for such testing as may be carried out on his premises in accordance with this specification. Failing facilities at his own works for making the prescribed tests, the maker shall bear the cost of carrying out the tests elsewhere.

TIMBER.

Plants are divided by botanists into two divisions: the Phanerogams and Cryptogams, the flowering and non-flowering plants.

It is the wood of the former division that is used for the arts. The phanerogams are divided into two classes, viz., endogens and exogens, the material from the latter being used for building purposes only.

On examining the stem of an exogenous tree, four parts are distinctly noticeable, viz.:—

1. Pith.
2. Medullary Rays.
3. Annual Rings { Duramen. Alburnum.
4. Bark.

The pith is in the centre of the tree, and about this the annual rings are formed in concentric layers. The bark is that part exposed to the air, and serves as a skin to protect the newly-formed parts of the tree. The medullary rays occur as spider-like lines, radiating from the pith to the newly-formed wood.

Pith or Medulla.—The pith is the first formed portion of the stem, and consists entirely of cellular tissue. When the plant is young the pith contains a large amount of fluid, which serves to nourish the various parts of the plant. On getting older, the carrying of the sap and moisture to the leaves, etc., is performed by the vessels of the woody fibre deposited about the pith, which now being of no further use, after a short time dries up and decays. The pith of all the branches is a prolongation of the pith of the main stem.

Medullary Rays.—The medullary sheath is a thin membrane composed of spiral vessels covering the pith, and lying between the latter and the first deposition of woody

fibre. The medullary rays are vertical layers of a muriform cellular tissue, branching from the medulla and radiating from the latter to the most recently formed layers of sapwood. They serve to convey a portion of the descending sap to the vessels in the interior of the tree, and also the necessary air to combine with the substance of the sap and complete the formation of the various tissues. The medullary rays continue to lengthen and perform their function when the pith and the first-formed layers of woody fibre have commenced to decay.

Annual Rings.—The annual rings are formed of cellular tissue and woody fibre, arranged in concentric circles about the pith. These rings are called annual because one layer is added each year. This is true in the temperate climates, where the seasons differ in a marked manner, and where also there is one lot of leaves per year; but in the tropical climates, where the leaves are often shed twice in the same year, there would be a corresponding number of rings added.

The formation of the rings takes place as follows:—In the spring a considerable quantity of moisture with other substances is absorbed by the tree from the soil; this is drawn up through the tubes of the alburnum or sapwood, and conducted from the roots to the extremities of the branches, where it helps in forming the leaves, from which a considerable quantity is evaporated, and a part turned into sap. At the same time the bark becomes loosened, and a glutinous fluid called cambium is secreted between the bark and the last formed ring of sapwood; this is gradually converted into the cellular tissue of the next annual ring, and is known as the spring layer.

Towards the end of the summer, and during the autumn, the woody fibre commences to grow from the upper part downward, forming the dark ring in each annual layer.

These fibres obtain their nutriment from the fluid of the cambium, and become attached to it; this is known as the autumn layer. During this time the moisture which has been turned into sap in the leaves descends in the outer layers of the tree, under the bark, being carried to the interior through the medullary rays, and so nourishing every part of the tree.

The first formed annual rings are gradually filled up with the substance carried in by the medullary rays and solidify, forming the duramen or heart-wood. In the living tree this is the first part to decay; decomposition commences at the pith and the oldest layers first, extending outwards. The heart-wood is the part used for constructional purposes, this being the most durable portion of the tree when converted.

The alburnum or sapwood should not be used for constructive or joinery work, as the juices and parts, not being properly hardened, readily decompose. The alburnum is easily distinguished from the duramen in the hard woods, it being usually of a lighter colour, and in the softer woods the colours vary.

The annual rings in trees grown in hot countries are not, as a rule, so distinctly marked as those grown in a temperate climate, but gradually merge one into the other; where the seasons are more marked, the rings are more distinct.

Bark.—The bark consists of cells and woody fibre; a fresh layer is deposited each year on the interior. The bark is to a certain extent distensible, and increases slightly in girth as the diameter of the tree increases by the rising of the sap, but in the course of a few years the older layers become split, and the outer layers scale off.

In some specimens of exogens the bark becomes very thick and spongy, as is the case with those that supply cork.

Time for Felling.—Timber cannot be used immediately after felling on account of the moisture it contains, which on drying would cause it to shrink.

The tree, therefore, should be cut down when the moisture in the tree is at its minimum, which in temperate climes is in midwinter.

A tree should be felled in its prime. If too young, there is too much sapwood; if too old, the wood is brittle and inelastic. Oak trees arrive at maturity in about 100 years, but they are often felled much before that age. The ash, elm, and larch should be felled when the trees are between 50 and 100 years old, and the poplar at between 30 and 50 years.

The spruce and pine in Norway are generally cut when between 70 and 100 years old.

Trees, on being felled, should be immediately stripped of their bark to allow of a more rapid evaporation.

The bark of the oak is valuable, and is generally stripped off when in its prime in the spring, and the tree is left standing until the fresh foliage has died. By this arrangement the sap under the bark expends itself upon the foliage, and the sapwood becomes much harder. This method of stripping the bark has been found to cause the oak to lose in a month all the water that would be lost on exposure to the air.

Trees should be cut to the scantling required soon after felling, to avoid large shakes occurring through shrinkage.

Seasoning.—Timber when felled should be stacked to season, in order to dry out all moisture and remove any sap that has not hardened. That part of the tree which has been thoroughly indurated requires very little seasoning, but in the part near the alburnum or sapwood the moisture requires to be thoroughly driven off before the wood is

used, or it will spoil the work by shrinking and induce decay.

Natural Method.—The best method of seasoning is to stack the timber in such a manner as to allow a thorough circulation of air about all its faces. This is best accomplished by placing the timber in sheds, with two at least of its sides covered to prevent draughts by checking any rapid currents of air; the timber should be placed perfectly level, so that it cannot twist, either by placing the pieces in racks or stacking them in tiers. This method takes the longest time to effect, but wood so seasoned is always more durable and reliable than that which is dried by any hastening process.

Water Seasoning.—Timber treated by this process dries much more quickly than by the former method. It consists in placing the material in a running stream, chained or tied down so that the timber is entirely submerged, otherwise there is likely to be a dirty line at the water level, and the timber is likely to cast from the unequal absorption of water; the stuff should also be placed with the butt end facing the current; the stream will then be flowing in the direction from the butt to the upper end of the log, the water being able to enter more readily into the pores when the wood is in this position than when in the reverse. It there dilutes the sap, and carries it out with it in its passage through the timber. Timber should not be submerged for a greater period than fourteen days, or its durability will be impaired. The timber when taken out is stacked, and left to dry either by the natural process, which is completed in a much shorter period than if not submerged, or it is placed in sheds and dried more quickly by raising the temperature; this, however, unless great care be taken, is liable to cause the timber to shake, by causing the exterior surfaces to dry and shrink

while the interior is full of moisture. Shakes are liable to occur for the same reason in large logs dried by the natural method; and those timbers, such as elm, most subject to this are often submerged to counteract this defect.

Desiccating consists in stacking the timber, usually in racks, in chambers heated, and kept at a constant temperature, varying from 80° to 100° Fahr. The time taken in seasoning by this method is reduced to about one-twelfth that required by the natural process.

The waste heat from boilers is generally utilized for this purpose.

Boiling and steaming are used as artificial methods of seasoning, but are said to reduce the elasticity and strength of the timber.

Smoke drying, scorching, and charring of timber tends to its hardness and durability.

Timber is considered to be fit for the carpenter when it has lost one-fifth of its weight, and for the joiner one-third of its weight after felling.

The following is a table showing the approximate time required for seasoning oak and fir timber under cover:—

Size.	Oak.	Fir.
24″ square and upwards ...	26 months.	13 months.
24″ ,, to 20″ square ...	22 ,,	11 ,,
20″ ,, ,, 16″ ,, ...	18 ,,	9 ,,
16″ ,, ,, 12″ ,, ...	14 ,,	7 ,,
12″ ,, ,, 8″ ,, ...	10 ,,	5 ,,
8″ ,, ,, 4″ ,, ...	6 ,,	3 ,,

Planks from one-half to two-thirds the above time, according to thickness.

Conversion.—The cutting up of logs to form balks, planks, deals, boards and battens is called conversion.

These may be cut longitudinally, tangential to the annual rings; this is the most economical method. But for harder woods, especially oak, the length cuts are often normal to the annual rings, or parallel to the medullary rays, and converge towards the centre (the residue after the boards have been removed consists of a number of pieces triangular in section, which may be used for weather-boardings, fencings, battens, etc.), the object being to obtain the maximum effect of the beautiful markings of the medullary rays. Wainscot oak is cut in this manner.

Planks cut with their depth tangential to the annual rings are found to be stronger as beams than those cut parallel to the medullary rays.

Timbers of the pine and spruce varieties (large quantities of which are imported into England from the countries around the Baltic) are usually converted before shipment, being sent to the market in the form of logs, balks, planks, whole deals, cut deals, battens, ends, masts, spars and poles, and prepared timber.

A log or stick is the trunk of a tree with the branches lopped off.

A balk is obtained by squaring a log.

Ends are short pieces of planks, deals, and battens under 8 feet long.

Masts have a circumference of more than 24 inches, spars and poles a circumference of less than 24 inches.

Boards are battens, deals, or planks under 3 inches thick.

Prepared timber is imported in scantling sizes, known as sawn timber, such as $4'' \times 2''$, $4'' \times 4''$, and many sizes used in building operations. A considerable quantity of wrought boarding also comes over in the form of weather-boarding, floor boards, matched and beaded boards, etc.

Classification of timber according to size:—

	in.		in.		in.		in.
Balk	12	by	12	to	18	by	18
Whole Timber	9	,,	9	,,	15	,,	15
Half	9	,,	$4\frac{1}{2}$	,,	18	,,	9
Scantling	6	,,	4	,,	12	,,	12
Quartering	2	,,	2	,,	6	,,	6
Planks	11	to	18	by	3	to	6
Deals			9	,,	2	,,	$4\frac{1}{2}$
Battens	$4\frac{1}{2}$	,,	7	,,	$\frac{3}{4}$	,,	3
Strips and Laths	4	,,	$4\frac{1}{2}$	,,	$\frac{1}{2}$	,,	$1\frac{1}{2}$

Pieces larger than planks, generally called timber; but sawn all round, called scantling; when of equal dimensions, called die square.

Buying of Timber.—Pine and spruce timber is sold by the standard hundred, the load, or by the square of 100 feet super. There are several standard hundreds in use, as follows:—

London ...	120	pieces	12 ft.	long	9 in.	by	3 in.
Petersburg ...	120	,,	6 ,,	,,	11 ,,	,,	3 ,,
Christiania ...	120	,,	11 ,,	,,	9 ,,	,,	$1\frac{1}{4}$,,

The Petersburg standard is the one most generally followed, and equals 165 feet cube; a load of timber is 50 cubic feet (hewn), so that there will be $3\frac{3}{10}$ loads in a standard. It will simplify calculation to commit to memory one or two facts relating to these measurements:—165 feet cube is 165 feet run of 12 in. $\times$ 12 in.

In dealing with a scantling of 12 in. $\times$ 4 in. its section is one-third of the 12 in. $\times$ 12 in., so that to make up a standard in that scantling it would require $165 \times 3 = 495$ feet run.

The price per foot run can be obtained in this way if the value of a standard is known, the cost of cutting being added.

Decay in Timber.—Decay usually commences with the decomposition of the albuminous substances contained by the timber. The two forms of decay most generally known are the dry rot and the wet rot. The former is a chemical decomposition caused by an external living agent in an imperfectly ventilated atmosphere, while the latter is a chemical decomposition of the sap and fibre of unseasoned wood, or if seasoned by exposure to the moisture of a temperate atmosphere.

Dry Rot is caused by the growth of fungi, the spores of which, floating about in the atmosphere, alight on timber when under favourable conditions, and these germinate, inserting their roots into the timber, the constituents of which they decompose, and so obtain their nutriment. These plants rapidly spread over the whole of the timber, and attack other timbers in the vicinity, causing them to crumble. The favourable conditions for dry rot are a warm humid atmosphere, insufficient ventilation, and the presence of any green sap in the timber. All stuff in constructional works should therefore be thoroughly seasoned before being used, and well ventilated when fixed.

Wet Rot is caused by the oxidation of lignin and other substances in the presence of air and water, the oxygen combining with the carbon to form CO_2, and with the hydrogen to form H_2O.

The hydrogen, however, becomes more rapidly oxidized than does the carbon, consequently the latter remains in excess, and a brown snuff-coloured powder results, which has a larger proportion of carbon than the woody fibre.

Moisture is necessary to the process, which takes place in the open air, 60° Fahr. being the most favourable temperature.

Preservation of Timber.—There are various methods of artificially preserving timber from decay : the sap may be

expelled by hydraulic pressure, and replaced by chemical fluids, or the timber may be saturated with some chemical fluid which will combine or act upon the albumen and prevent its decay. The following are some of the artificial processes:—

Bethels.—The timber is impregnated with *creosote*, or oil of tar, from which the ammonia has been expelled, the effect being to coagulate the albumen. The oil may be either forced in the end grain of the timber, or soft woods may be immersed in a tank of hot oil.

The usual process is as follows:—Well-seasoned timber is placed in iron cylinders, from which the air is sometimes exhausted, and the creosote is forced in at a pressure of from 60 lbs. in the summer, to 160 lbs. to the inch in the winter. The amount of creosote required is from 10 lbs. to 12 lbs. per cubic foot.

Boucherie.—In this process the sap is expelled by fluid pressure, and a solution of copper sulphate ($CuSO_4$) is forced in the end grain of the wood.

Kyanizing consists in immersing the timber in a saturated solution of corrosive sublimate, $HgCl_2$ (mercuric chloride); this forms an insoluble compound with the albumen.

Blythe's process, also called *carbolizing*, consists in extracting the sap and water from the timber, and driving carbolic or tar acids (C_6H_5OH) through.

Burnettizing.—The timber is immersed in a solution of zinc chloride ($ZnCl_2$), or the fluid may be forced through the pores of the wood by pressure. This tends to harden the wood, and renders it partially incombustible.

All these processes depend upon the natural properties of timber; dense woods are less porous, therefore they are not so easily treated as softer woods. It has been found that when

a fluid was forced into the wood under pressure, it travelled over one hundred times more quickly longitudinally with the fibres than it did transversely, thus illustrating the difference between the structure of wood "with the grain" and "across the grain."

Defects in Timber.—The following are the defects most common in timber:—

Cup Shakes separate the whole or part of one annual ring from another.

Star Shakes radiate from the centre of the tree, increasing in width at the outside edge of the tree.

Heart Shakes are clefts or wide splits running right through the heart of a tree.

Rind Galls are peculiar curved swellings, caused generally by the growth of layers over the wound remaining after a branch has been imperfectly lopped off.

Upsets are portions of the timber in which the fibres have been injured by crushing.

Foxiness is a yellow or red tinge caused by incipient decay.

Doatiness is a speckled stain found in beech, American oak, and other timbers.

Twisted fibres are caused by the action of a prevalent wind turning the tree constantly in one direction. Timber thus injured is not fit for squaring, as so many fibres would be cut through.

Druxiness is the name given to decayed spots or streaks of whitish colour in timber.

Waney timber is the name given to cut timber showing at its angles that the rounded edges of the logs have been left on, so that the greatest possible rectangular section may be obtained with the least waste.

Characteristics of Good Timber.—In the same species that specimen will in general be the strongest and the most durable which has been the slowest in its growth, as shown

by the narrowness of the annual rings. The cellular tissue of the medullary rays should be hard and compact, and when cut with a saw the woody fibres should not present a woolly appearance or clog the saw, but should appear firm and shining, emit its characteristic odour, and when struck give a clear ringing sound.

Amongst different species of trees the strongest timber is yielded by those flourishing in tropical climates, and amongst trees of the same species those grown in the cold climates.

Varieties of Timber.—The timber used in building operations is nearly all imported. Norway, Sweden, Russia, and North America all supply the English market; as regards the distinguishing "brands," the following rules will generally apply:—Canadian woods are stencilled with black letters and white letters on ends, and red sorting marks on edges near the ends. Norwegian woods are generally stencilled with blue letters. Swedish woods are stencilled with red letters or marks on the ends. Woods from Russia and Finland ports are usually "dry stamped" or "hammer branded" on the ends.

The weights given for the various timbers, unless specifically stated, are for unseasoned timbers.

The timbers in use for constructional and general work are classified under two heads—1st, the needle-leaved or cone-bearing trees; 2nd, the broad-leaf trees.

The first section includes the pines and spruce as follows:

Northern Pine (Pinus sylvestris).—This timber is obtained largely from the following ports: Memel, Dantzic, and Stettin in Prussia; St. Petersburg, Riga, Onega, Archangel, and Narva in Russia; Christiania and Dram in Norway; Gefle and Soderham in Sweden. It is also extensively grown in Great Britain, being known here as Scotch fir. It is of a light yellow colour; the annual rings are clearly defined, consisting of a light and a dark portion; they are

regular and about $\frac{3}{16}$ inch in thickness; medullary rays not visible; straight grained; weighs about 36 pounds per cubic foot; contains resinous substances which render it durable; it is strong and elastic; does not warp nor shake to any extent; is easy to work, and cuts clean and short. This wood is largely used for constructional work and for joinery, being suitable both for internal and external work.

American Yellow or White Pine (Pinus strobus).—This timber is exported from Quebec, St. John's and Shedac, and a few other Canadian ports. It is sometimes known as Weymouth pine. It is of a whitish or pale yellow colour, annual rings not very distinct; they are regular and about $\frac{1}{4}$ inch in thickness; medullary rays not visible; it is very straight grained; weighs about 29 pounds per cubic foot; is not as strong nor elastic as northern pine; does not warp much, but is liable to shake; is very easy to work, and is used chiefly in joinery work for mouldings and wide panels; it does not prove durable when used externally.

This timber is exported in logs and deals. The first quality of deals is the "1st bright"; "floated" and "dry floated" are inferior classes.

Brights consist of deals sawn from picked logs, and shipped straight from the saw mills.

Floated deals are floated in rafts down the rivers from the felling grounds to the shipping ports.

Dry floated deals are those which, after floating down, have been stacked and dried before shipment.

Red Pine (Pinus resinosa), exported from North America, and known as Canada Red Pine. The wood is white, tinged with yellow or straw colour, has a clean, fine grain, and works up to a surface having a smooth, silky lustre, weighs about 35 pounds per cubic foot. Is used extensively for internal joinery, and is durable where well ventilated.

Glue adheres well to the wood, and it is greatly used by cabinet-makers for veneering upon.

Sequoia Pine, from California, straight grained, and easily worked ; used for internal joinery. This wood is reputed to shrink in the direction of its length.

Kawrie Pine (Dammara Australis) from New Zealand, of yellowish-white colour ; it possesses a silky straight grain ; is generally free from defects ; light, strong, and elastic, and is good for joinery, and weighs about 33 pounds per cubic foot.

Pitch Pine (Pinus rigida).—This timber grows in the south-eastern States of North America, is shipped chiefly from the ports of Savannah and Pensacola. It is of a dark yellow or light reddish-brown tint ; annual rings clearly defined and of a uniform width of about $\frac{3}{16}$ inch ; medullary rays not visible ; it is straight grained, and can be obtained in great lengths ; is highly charged with resinous substances, rendering it very durable ; weighs about 46 pounds per cubic foot ; it is very strong and, compared with other pines, difficult to work ; has a tendency to stick to the tools on account of its large quantity of resin. It is subject to heart and cup shake, shrinks considerably in drying, and also tends to warp.

The straightness of grain, great strength, and large scantling render it valuable for constructional work ; it is largely used for piles and for ornamental joinery work on account of the beautiful figure of its grain, although its excessive shrinkage renders it unsuitable for this purpose.

White Fir or Spruce (Abies excelsa).—This wood is obtained chiefly from the following ports : Onega, Narva, and St. Petersburg in Russia ; Christiania, Dram, and Frederikstad in Norway ; and Gothenburg, Sandsvall, and Hernosand in Sweden. It is of a whitish or very pale

yellow colour; annual rings clearly defined, uniform, and about $\frac{3}{16}$ inch in thickness; medullary rays not visible. The wood is usually straight grained, weighs about 32 pounds per cubic foot, contains resinous substances, but not to the same extent as northern pine. It is strong and elastic; it warps and splits in drying; is tough but easy to work when free from knots, which in this wood are very hard; it cuts clean and free with the saw, and finishes with a silky lustre from the plane, and is sufficiently close grained to take a polish. The best kinds of this wood are used largely for internal joinery work; it is not durable when used externally; the coarser varieties are used for packing-cases, and for similar rough purposes. It has a beautiful figure, and is often varnished in order to enhance its appearance. It is much used for constructional work, but is neither as strong nor as durable as northern pine.

Cedar (Abies Cedrus).—From Asia and America. Is of a reddish-brown colour, porous, soft, and of light weight; has a pleasant odour, which is, however, obnoxious to insects and vermin, and is therefore suitable for furniture. It works easily, shrinks little, and is used for patterns, carved toys, pencils, and boat-building, and weighs about 28 pounds per cubic foot.

Larch (Genus Larix).—From Europe and America. Of honey-yellow or brownish-white colour, the toughest and most lasting of the coniferous order; has straight grain and is free from knots, but is very liable to warp, shrinks very much, and is extensively used for posts and railway sleepers. It weighs about 40 pounds per cubic foot.

The second section includes oak, mahogany, etc.

Oak (Quercus).—The timber abounds in Europe (including Great Britain), Asia, and America. There are a great many species of oak, but all have the same general characteristics, differing only in minor details.

There are two kinds native to this country, viz. Q. pedunculata and Q. sessiliflora; the chief difference between the two lies in the arrangement of the flowers and leaves.

The former is generally supposed to be the more durable; the latter is credited with being tougher and more difficult to rend, and can be obtained in greater lengths, and is straighter grained than the pedunculata; it is light brown in colour; annual rings distinct and generally fairly uniform, about $\frac{1}{8}$ inch in thickness; medullary rays strongly marked; grain fairly straight, but in trees grown in the open usually gnarled and twisted; weighs about 51 pounds per cubic foot. It contains gallic acid, which rapidly corrodes ironwork, thus preventing the general employment of these two materials together; it is subject to warping and shaking; is very tough and difficult to work, but will take a high finish. It is greatly prized for ornamental joinery work on account of its figure and the beautiful markings of the medullary rays when the log is cut lengthwise radially; it is very durable and strong, and therefore valuable for heavy constructional work; it is very durable in either a wet or a dry situation, and proves more durable than most other woods in an alternately wet and dry position.

Baltic Oak is inferior in quality to the English, and is generally of a straighter grain. It is imported in logs 10 to 16 inches square, and planks 2 to 8 inches thick, and weighs about 53 pounds per cubic foot.

American white oak can be obtained in larger sizes than any of the other kinds, and is not supposed to shrink as much in seasoning; it is straight grained, but not so durable as the English oak, and weighs about 62 pounds per cubic foot.

Mahogany (Swietenia mahagoni).—Mahogany is obtained from the West Indies and Central America, the chief supplies coming from Cuba and Honduras. Mahogany is

of a reddish-brown colour ; annual rings not very distinct, but uniform ; medullary rays invisible ; fairly straight grained, weight (Cuba) about 53 pounds per cubic foot, (Honduras) about 35 pounds per cubic foot. It is strong, but inclined to be brittle; it warps, shrinks, and shakes very little; it is hard, not very difficult to work, and is capable of receiving a high finish and a splendid polish.

The wood lasts well when used internally, but is not durable when employed for external purposes; it is chiefly used for cabinet work and ornamental joinery, for shop fittings and internal finishings. Cuba or Spanish mahogany, as it is sometimes called, is darker and richer in colour than the Honduras, and has a more wavy grain than the latter, which produces when cut a beautiful figure; this renders it very durable for the highest classes of joinery work. It is harder and denser, but does not attain such large dimensions as the Honduras. The Cuba may be easily distinguished from the Honduras by a chalk-like substance filling its pores. The Honduras is chiefly noted for the straightness of its grain, rendering it particularly adaptable for sticking mouldings. It is used for all kinds of internal joinery and cabinet work; is largely used for pattern-making on account of the small amount of its shrinkage; it is sometimes known as bay-mahogany or bay-wood.

Walnut. 1st (Juglans regia), from Britain, unsuitable for beams, but used for ornamental joinery. It weighs about 44 pounds per cubic foot.

2nd (Juglans alba), the white walnut from North America, very tough and flexible, and weighs about 51 pounds per cubic foot.

3rd (Juglans nigra), from America, heavier, stronger, and more durable than European walnut. Not subject to the attack of worms, is of fine grain, and will polish well, and weighs about 57 pounds per cubic foot.

Teak (Tectona grandis) is very durable wood for all work exposed to the weather; it is exported from Burmah and other places. The exceptional straightness of grain renders it easy to work, but the fibres have a great tendency to split up in a longitudinal direction. It contains a resinous aromatic oil, which makes it very durable, and enables it to resist the white ant and worms, and tends to preserve iron fastenings; it weighs about 49 pounds per cubic foot.

Elm (Ulmus Campestris).—This timber is grown in large quantities in England. It is of a brown colour; annual rings distinct; medullary rays invisible to the eye; has a very twisted grain, not easily rent; weighs 37 pounds per cubic foot; it is very liable to warp and shake; is very tough and difficult to work; it is very durable when kept either thoroughly wet or perfectly dry. It is used chiefly for the sides and bottoms of carts, the hubs of wheels, for coffins, wood pulley-blocks, and for all similar purposes requiring a tough, strong wood.

Ash (Fraxinus).—This timber is obtained in large quantities in Great Britain. It is of a light brown colour; annual rings distinct; medullary rays not visible; is straight grained; weighs 52 pounds per cubic foot, and is very tough, strong, and elastic; is subject to shake in seasoning; durable if properly seasoned; has a large proportion of sap-wood, but is very subject to the attack of worms. Its great elasticity debars its use for all large structural operations, but it is valuable as shafts for hammers, spokes for wheels, for oars, and in any position where it will be subject to sudden stresses.

Birch (Betula alba), from Europe and America. Light brown, hard, plain, and even in grain, is easily worked, but is neither strong nor durable, and is not used for building purposes, but by chair-makers, cabinet-makers, and

turners. It weighs when seasoned about 45 pounds per cubic foot.

Beech (Fagus).—Large quantities of beech are obtained in England. It is of a light reddish-brown colour; annual rings distinct; medullary rays strongly marked, can be obtained in great lengths and is very straight grained; weighs 43 pounds per cubic foot; is strong, tough, and durable if kept dry; is close grained and easy to work, and will take a high finish. It is largely used for furniture, and owing to its close and even grain is valuable for tools which require an even wearing surface. Used for cogs in machinery wheels.

Basswood (Tilia americana).—This wood is obtained from the United States and Canada. It is of a yellowish-white colour; annual rings indistinct; medullary rays invisible; is straight grained and of a uniform substance, soft and easy to work, and is of a very uniform grain and may be cut easily across or in any direction of the grain. It is largely used for cabinet work and also for carving.

Lime (Tilia europæa).—Obtained plentifully in England. It is of a whitish colour; annual rings distinct; medullary rays invisible; very straight grained and uniform in density, very soft and easy to work in any direction. It is largely used for cabinet work and for fine carvings, and weighs about 33 pounds per cubic foot.

Poplar (Genus Populus), of a yellowish or brownish white colour, texture uniform. Light, soft, easily worked and carved, only indented, not splintered, by a blow. It should be well seasoned, and when kept dry is tolerably durable. It weighs about 33 pounds per cubic foot.

Chestnut (Castanea vesca) from Europe and America, is of low growth, and of similar appearance to oak, but has no alburnum nor sapwood, and the medullary rays are not

easily seen. It attains great dimensions, but is only used for common work, such as posts and rails, and weighs about 41 pounds per cubic foot.

Hornbeam, from Britain. White colour, close grain, tough, hard, strong, and of moderate weight; is specially useful for cogs in machinery. It weighs about 52 pounds per cubic foot.

Sycamore (Acer Pseudo-Platanus).—This timber abounds in England. The wood is sometimes known as the common or great maple. It is brownish or yellowish-white in colour; annual rings distinct; medullary rays small but distinct, often has a beautiful figure; fairly strong, and difficult to work; weighs about 38 pounds per cubic foot, is durable when kept dry. It is used chiefly for furniture and ornamental joinery.

Greenheart (Nectandra rodixi), a strong and durable timber from British Guiana. This timber resists the attacks of the sea worm, and ranks next to teak for resisting the attacks of the white ant, and is well adapted for planking vessels, piles, and structures under water. It requires careful working, being liable to splinter. It weighs about 62 pounds per cubic foot.

The following are a few of the leading European ports exporting timber for the English market:—

Norway.—Christiania, Drammen, Frederikstad.

Sweden.—Gothenburg, Soderham, Gefle, Sunderswall, Stockholm.

Prussia.—Memel, Dantzic, Stettin (yellow planks and deals).

Russia.—St. Petersburg, Archangel, Riga (white deals only), Onega.

American Ports.—Quebec (yellow deals), St. John's (spruce), Richibucts, Shedac, Miramichi.

Expansion of Timber.—Expansion along the grain when dry, when the temperature had been raised from 32° to 212° Fahr., according to Mr. Joule ("Pro. Roy. Soc.," Nov. 5th, 1857) :—

Baywood	·000461 to ·000566
Deal	·000428 ,, ·000438

Moisture diminishes, annuls, and even reverses the expansibility of timber by heat.

Professor Rankine also gives the expansion of following metals under similar conditions :—

Wrought Iron and Steel	·00114 to ·00125
Cast Iron	·00111
Lead	·0029
Zinc	·00294

Timber is better than any other material to resist alteration in length when acted upon by increase of temperature.

Under usual changes of temperature, timber has the following :—

Variations in depth and width.

Fir $\frac{1}{360}$ to $\frac{1}{75}$ of its width, mean $\frac{1}{124}$
Oak $\frac{1}{412}$,, $\frac{1}{83}$,, ,, ,, ,, $\frac{1}{140}$

Strength of Timber.—The strength of dry timber to resist crushing (tons per square inch) :—

Northern Pine	2·25
Spruce Fir	2·25
English Oak	3·6
Canadian Oak	2·75
Pitch Pine	3·0
Yellow Pine	2·4
Teak	4·7

Tensile strength of timber (tons per square inch), Laslett—

Fir Spruce	1·8
English Oak	3·25
Northern Pine	1·5
Teak	1·5

Cross Strength of Timber.—The following is the value of K, that is, it is the table of breaking weights of wood beams 12 inches long, 1 inch broad, 1 inch deep, when loaded in the centre and supported at ends.

VALUE OF K.

Material.	Central breaking weight in cwts.
Ash	6
Elm	$3\frac{1}{2}$
English Oak	$4\frac{1}{2}$
Baltic Oak	$3\frac{1}{4}$
Canadian Oak	5
Pitch Pine	5
Northern Pine	4
Spruce Fir	$3\frac{1}{2}$
Teak	$5\frac{1}{2}$

Authorities differ considerably as to the absolute strength of timber, the nature of the grain, and the amount of moisture in the wood which influences the strength, hence one-fifth of the breaking weight is the highest load that should be placed on timber; one-tenth is often taken for pillars, storey posts, etc., or a sliding value is given to the factor of safety, as stated in the chapter on Pillars.

PAINTS AND VARNISHES.

Definition.—Paint is an impervious coat laid on the surfaces of building materials to protect them from the effects of the atmosphere, and also for ornamental purposes.

Paints are composed of four parts—the base, vehicle, solvent, driers, to which is often added a colouring matter called a pigment.

Base.—There are several bases used for paints, many of them for special purposes. The following are the four most commonly used in building work:—White lead, red lead, zinc white, and oxide of iron.

White Lead is a basic lead carbonate $2PbCO_3$, $Pb(OH)_2$, and is that mostly used as a base for painting all ordinary building work. It has a greater covering power than any other base, and weathers well; but it is liable to become discoloured by sulphuretted hydrogen (H_2S), and is very poisonous. It frequently contains a small amount of iron, which turns it to a yellow colour. There are two methods of manufacturing white lead: First, by placing sheets of lead (Pb) in tan, and subjecting them to the fumes of acetic acid (CH_3COOH); this has the effect of covering the sheets with a crust of the carbonate, which is removed and ground to a fine powder, and a fresh surface of the lead exposed to the fumes of the acetic acid; this is known as the Dutch method. Secondly, by dissolving lead mon-oxide (PbO) in acetic acid, and then forcing carbon dioxide (CO_2) contained in the smoke of a coke fire with chalk through the lead acetate, $Pb(CH_3COO)_2$. White lead may be obtained as a powder or mixed with about 8 per cent. of linseed oil.

Adulterants.—White lead is adulterated with the following substances:—Lead sulphate, chalk, whiting, barium sulphate.

Barium sulphate ($BaSO_4$) is the adulterant most commonly used, and if not added in excess is not detrimental, as it gives opacity to the base. It has a greater specific gravity than white lead, which makes its detection easy, if used singly in large quantities; but it is often mixed with whiting, the specific gravity of which is comparatively low, so that the weight of the whole mass may be adjusted. Under these conditions it can only be detected by a chemical test; this may be done in the following manner:—The

compound is treated with diluted nitric acid, HNO_3 which dissolves the lead and leaves the barium sulphate, which is insoluble in the above acid. If the compound be ground in oil, the oil must be driven off by heating before applying the acid.

White Lead should be covered, as exposure to the air turns it grey, and should be kept a considerable time before using. If used too fresh, it acquires a yellowish tinge.

Red Lead, or minium, is tri-plumbic tetroxide (Pb_3O_4), used chiefly as a priming coat for wood, and also as a base for some red paints. It is not durable if exposed to acids, foul air, or metallic salts; other oxides of lead and white lead alter its shade of colour. It is prepared by heating lead in an open furnace, thus forming litharge (PbO), and then heating it a second time, when it takes up more oxygen, forming Pb_3O_4.

Zinc White (ZnO) is an oxide of zinc; it is superior to white lead as a base for paints, for chemical works, or where sulphuretted hydrogen exists, as its colour is unaffected by the latter, the zinc sulphide formed being white; but for general work it is inferior to white lead, because it does not weather so well, nor mix with oil with the same facility, nor cover so great an area as a lead base. It is prepared by burning zinc in a retort, through which a current of atmospheric air is passed. The zinc oxide passes into a receptacle, in which it is collected and compressed to make it more dense.

Magnetic Oxide of Iron (Fe_3O_4) is used as a base in paints chiefly for covering iron work. It is supposed to be better for iron work, as no voltaic action can be set up between the base of the paint and the metal to be covered. It is prepared by roasting and grinding a brown hæmatite ore, consisting principally of iron oxide and silica.

Vehicle.—A vehicle is a liquid of a drying nature, capable of dissolving and holding bases and pigments in suspension, and to enable the paint to be laid on in thin and uniform coats, and to enter the pores if it be a porous material, where it hardens, and thus forms a durable and impervious skin. For oil colours, such as the ordinary paint, the vehicles are oils, but for whitewash or distemper water is used.

The vehicles chiefly used for paint are linseed, poppy, and nut oils, which belong to the class known as fixed oils.

Linseed Oil is most commonly used for all ordinary work; it is obtained from the flax plant by crushing the seed, heating it and forcing the oil out in hydraulic presses; it is then allowed to stand, and the clear oil is drawn off. This is known as raw oil; it is transparent, with a slight amber tint, and improves in drying and colouring properties by keeping several years. It is useful for delicate tints, and therefore for internal work. Linseed oil is often boiled before use by heating it to about 90° with drying substances, such as red lead and litharge, and then raising the temperature to about 200°, at which it is kept for three or four hours, when it is allowed to stand, and the albuminous matter it contains settles and is then separated. Boiled oil is much thicker and darker than the raw oil; it dries more rapidly, and has a greater body, is more durable, and is therefore more suitable for external work.

Poppy Oil is obtained by pressing poppy seed. It is often used for delicate colours, being clearer than the linseed oil, but it is inferior to it in drying and tenacious properties.

Nut Oils are used by painters because of their cheapness, but as they are inferior in every respect to both linseed and poppy oil their use is limited to inferior work.

Solvent.—Turps is added to paint primarily as a solvent, and also to dilute it to work more freely.

Turps or Oil of Turpentine ($C_{10}H_{16}$) is a volatile oil prepared by distilling turpentine, a resinous substance, obtained by tapping trees of the coniferous order. It dries partly by evaporation and partly by the absorption of oxygen, the result being a resinous body.

It is used with the base without the oil when the glossy surface left by the oil colour is not required; a coating of such colour is known as a flatting coat.

Driers.—Linseed oil dries by the absorption of oxygen; this may be greatly accelerated by adding substances containing a large proportion of that element. Driers are supposed to act either by parting with some of their oxygen, or by enabling the oil in some way to combine with the oxygen of the air, the latter being the more probable.

The following are some of the substances used for this purpose:—Litharge, lead acetate, zinc sulphate, manganese dioxide, and red lead.

Litharge (PbO), an oxide of lead, is most commonly used. Massicot, a superior kind of litharge, is prepared by heating the lead to a degree just insufficient to fuse the oxide.

Lead Acetate.—$(CH_3COO)_2$ Pb, ground in oil is used as driers for the lighter tints.

Red Lead.—Pb_3O_4, which is lead oxide, is often used as driers when its colour does not affect the tint, but it is less powerful in its action than litharge.

Manganese Dioxide.—MnO_2, is quick in its action, but can only be used for the deep tints, as it is of a dark colour.

Zinc Sulphate.—$ZnSO_4$ and *Manganese Sulphate* ($MnSO_4$) are used as driers for zinc paints. No driers containing lead should be used for a paint with a zinc base, as a voltaic action would be set up.

Driers should not be used with pigments that dry well, nor in excess, which retards the action of drying; they should not be added till the colour is about to be used.

Terebene is a solution of one of the driers in oil of turpentine. It is used in paints that are required to dry quickly.

Pigments are colouring matters finely ground, used to give opacity and colour to paint for ornamental purposes. They are prepared from earthy, metallic, and animal substances in two forms, either as a finely ground powder, mostly used for tinting distemper, or ground in oil for tinting oil paints.

In estimating painters' work the cost will largely depend upon the pigment used, some pigments being more expensive to produce than others. For convenience they are usually classified under three heads, viz.:—

Common Colours, which comprise such as lampblack, red lead, white lead, Venetian red, greys, ochres, and umbers.

Superior Colours, blues, warm tints, light yellows, mineral greens.

Delicate Tints, pea green, verditer, bright blues, rich reds, and pinks.

Tar.—A substance obtained by the distillation of the wood of pine trees, and also in the distillation of coal for the manufacture of gas, the tar being a by-product; it is often used for forming a paint for preservative purposes only. The tar is mixed with turps and linseed oil or slack lime. A small quantity of pitch, which is obtained by distilling tar, is added in hot weather to prevent the tar from running; a little lime answers the same purpose.

Fire-resisting Solutions.—Asbestos paint possesses the valuable property of retarding the action of fire, and for that reason has been largely adopted for public buildings.

Coatings of sodium tungstate also retard the action of

fire, and have in some instances resisted the action of fierce fires for as long as twenty minutes shortly after application.

Wherever timber work in fire-resisting constructions is accessible, it may with great advantage be coated with either of these solutions.

Varnishes.

Varnish is a solution of resinous gums dissolved either in oil, spirits, or water. It is used to preserve painted work exposed to the weather, and also to improve the appearance by covering it with a shiny transparent coat of resin. It is applied to wall papers and joinery work in woods with a beautifully marked grain, to preserve and improve their appearance.

There are several kinds of gums used for making varnish, the three principal kinds used for building work being amber, gum animé, and copal.

Amber is a transparent yellow substance found in Prussia and on the coasts of the Baltic; it is hard, durable and tough, difficult to dissolve, slow in drying, and keeps its colour well.

Gum Animé is the name applied to copal, and is frequently found in rounded masses embedded in sandy soil; is imported from the East Indies; is durable, tough and hard, dries quickly, but is subject to cracking.

Copal is imported from the East and West Indies. It is generally considered the best; is very durable for external work, and is tough and hard.

Driers.—Usually litharge or lead acetate is added to accelerate the drying. Lead acetate is generally considered to be the best, as it combines with, as well as hardens, the varnish. An excessive use of driers injures the varnish and impairs its durability. Good varnish should be quick-drying, hard and tough; should have a good gloss and weather well.

French Polish is a varnish formed by dissolving shellac, a resinous gum, in spirits of wine, and is worked upon the surfaces of hard woods to heighten the effect of the grain. It is applied by rubbing on to the surface of the wood with wadding enclosed in linen rag.

Wax Polish.—Beeswax in its simple state is rubbed into the pores of the wood, being worked in with rubbers of linen rag, a little turps being added to the rag rubber to make it work more freely. This forms a dull polish on the surface; it is considered far superior, is more durable, and takes longer to accomplish than the French polishing.

Whitewash is made from pure lime mixed with water; it is chiefly used for sanitary purposes; it should be laid on while hot.

Whiting is made by mixing pure white chalk with size and water; it is used for whitening ceilings and walls.

Distemper is the name for all colouring matter, usually earthy pigments, such as ochre, umber, Indian red, and lampblack, mixed with size and water.

Clear Cole.—A size coating applied to fill up the pores of wood or plaster preparatory to distempering or painting.

Putty is made with whiting reduced to a fine powder and mixed with raw linseed oil.

Painter's Tools.—Figures 30 to 62 show the common tools of the painter and decorator:—

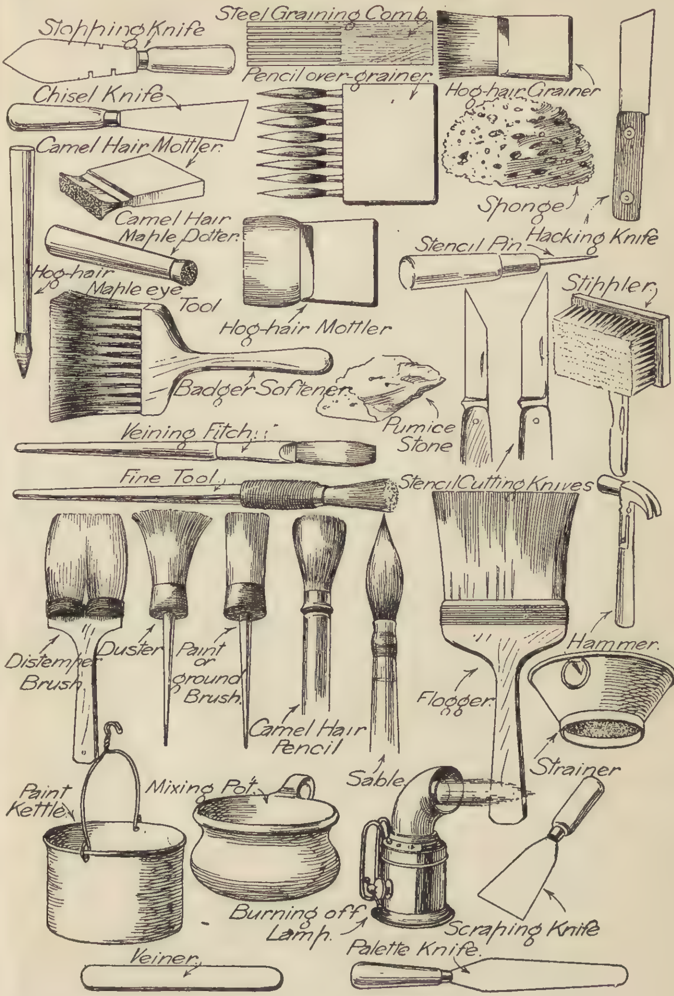
The mixing pot, palette knife, the strainer, and the paint kettle for the mixing and holding of colour.

The sponge, pumice stone, burning-off lamp, and chisel knife, for the removing of and cleaning down paint.

The scraping or stripping knife used for stripping old paper from walls.

The hammer, hacking, and stopping knives for clearing out broken glass and fixing new.

The stopping knife, two knot distemper brush, used for



Figs. 30—62. Painter's Tools.

clearcoling and distempering; the duster for removing dust preparatory to applying paint; the ground brush for broad surfaces; the tool for cutting in edges; the fitch and camel-hair pencil for lining and picking out small members; the sable for gilding; the flogger for picking up leaf gold; and a large rectangular brush, with a handle, termed a stippler, for producing a non-streaky rough surface; the stencil cutting knives and stencil pin.

The following tools are used in graining: the steel graining comb, the hog-hair grainer, the pencil over-grainer, the camel-hair mottler, the camel-hair maple dotter, the hog-hair maple eye tool, the hog-hair mottler, the badger softener, the veining fitch and veiner.

GLASS.

Glass.—If a mixture of sand and caustic soda (NaOH), or caustic potash (KOH) be fused a silicate is formed, which is homogeneous and transparent. Similarly with a mixture of sand and lime, or of sand and lead oxide, a transparent liquid is formed on fusion. When these silicates are cooled they do not form transparent solids, but are crystalline and brittle. If these two silicates are mixed and fused, the mass, when it cools, is a hard transparent glass.

Window glass is made as (1) Crown, (2) Sheet, (3) Plate glass, and all of these are silicates of soda and lime.

The ingredients used in the preparation of crown and sheet glass are as follows:—

Sand	100 lbs.
Sodium Sulphate	40 to 45 ,,
Chalk or Limestone	40 ,,
Powdered Anthracite Coal	2 ,,
Cullet (broken glass of the same kind) ...	100 ,,

The introduction of a small quantity of arsenic has the effect of rendering the glass colourless.

Bailey gives upon analysis the composition of a number of different forms of glass as follows :—

	Silica.	Potash.	Soda.	Lime and Magnesia.	Lead Oxide.	Alumina and Oxide of iron.
Bottle glass (ordinary)	65·6	2·7	4·9	20·4	—	6·1
Window glass ...	70·7	—	13·3	13·4	—	1·9
Flint ,, ...	50·2	11·2	—	—	38·1	0·5
Fusible ,, ... (for chemical apparatus)	70·5	2·1	17·2	8·7	—	1·0
Infusible glass ... (for combustion tubes)	73·1	11·5	3·1	10·7	—	0·9

Crown Glass.—The workman takes at the end of a blowpipe a bulb-shaped mass of about 10 lbs. of glass, in a viscous state. By blowing through the tube the mass is elongated, and by further blowing it afterwards assumes a flat vase-shaped mass with a bullion point. The mass is then transferred upon a cup shaped piece of metal which encloses the bullion point and which is carried by an iron rod, known as the ponty, and is taken in front of a furnace, where the rod is at first rotated slowly and then more rapidly, the rim of the vase expanding horizontally till at last it falls into and assumes a flat circular plate with a bull's-eye boss at the centre.

Sheet Glass.—The process of manufacture is as follows: A mass of molten glass of about 10 lbs. is gathered at the end of a tube and blown out to a pear-shaped mass, then by blowing and swinging simultaneously the mass lengthens and assumes a sack-shaped hollow cylindrical form, the air in the interior is rarefied, resulting in an end collapsing, the edges are then flashed over, after which the upper portion is cut off by a hot string of glass, and the cylinder which remains is cut by a diamond. The cut cylinder is then placed on a flattening kiln, when gravity in this state causes it to fall flat, after which it is taken to a furnace and annealed. Sheets to the dimension of 10 feet by 4 feet have been made by

this method. The usual sizes of sheets are from 12 to 17 feet in area, and the weight from 15 to 42 ozs. per superficial foot.

The largest sizes that are usually made in the various substances of sheet glass are as follows, but the extreme limits of length and width cannot be combined in the same sheet :—

	Extreme length.	Extreme width.	Extreme Area.
15 oz.	60 inch.	40 inch.	15 feet.
21 ,,	90 ,,	50 ,,	26 ,,
26 ,,	90 ,,	50 ,,	25 ,,
32 ,,	85 ,,	48 ,,	21 ,,
36 ,,	70 ,,	44 ,,	17 ,,
42 ,,	70 ,,	44 ,,	15 ,,

The extreme area taken in connection with the extreme length or width required in any particular case will indicate approximately the corresponding limit of width or length.

Patent Plate is the name given to sheet glass by the cylinder process ground and polished. It is higher in price than rolled plate, but its lightness and purity are valuable advantages for purposes of glazing picture frames and for photographic negatives. It may be obtained of the following thicknesses : $\frac{1}{16}$ inch, $\frac{1}{12}$ inch, $\frac{1}{10}$ inch, and $\frac{1}{9}$ inch ; and up to 50 inches long or 39 inches wide, and 13 feet in area.

Plate or British Plate Glass.—The processes are as follows : —1. Casting ; 2. Grinding ; 3. Smoothing ; 4. Polishing.

1. Upon a smooth iron table are placed about the edges rectangular fillets to the thickness of the plate about to be cast, the molten glass is then poured upon the table, and a roller being worked upon the fillets reduces the mass to the level of the fillets.

2. Grinding consists in placing a rubbing plate of cast iron upon the cast glass, and both glass and plate are made to move, water is introduced between, and later powdered emery.

3. After which the glass plates are smoothed, which consists in placing two glass plates and rubbing each against the other with fine emery between.

4. Polishing is done by machinery, the rubbers having epicycloidal motion imparted to them.

The constituents of plate glass may be as follows :—

Fine Sand	100 lbs.
Refined Sulphate of Soda	42 ,,
Carbon in powder	$2\frac{1}{2}$,,
Carbonate of Lime	20 to 25 ,,
Arsenic...	8 ozs.
Cullet (broken glass of the same kind) as may be desired.	

Sheets may be cast from $\frac{3}{16}$ inch to 1 inch in thickness, and up to 100 feet in area.

Rough Plate.—If the plate glass is not polished it is known as rough plate.

Rough Rolled Plate.—Plates are cast with a series of fine grooves or flutes, varying from 4 to 11 to the inch, as in Hartley's rolled plate, or patterns may be worked upon the table. This will give corresponding impressions upon the cast plate.

Classification of Glass.—The following gives a classification of glass in common use.

1. Crown Glass (Newcastle Glass).
2. Sheet Glass—(*a*) Plain.
   (*b*) Fluted Sheet.
   (*c*) Dappled Sheet.
   (*d*) Corrugated Sheet.
3. Patent Plate.
4. Plate or Cast Glass—(*a*) Rough Cast Plate.
   (*b*) Rolled Plate: Plain, Small Fluted, Large Fluted, Diamond, Small Quarry, Large Quarry.
   (*c*) Chequered Plate.
   (*d*) Wired Rolled.
   (*e*) Rolled Cathedral.
   (*f*) Polished or British Plate.
5. Coloured Glass—(*a*) Flashed.
   (*b*) Pot Metals.
   (*c*) Cathedral Tints.
   (*d*) Stained Glass.

WEIGHTS OF VARIOUS MATERIALS.

Materials.	Specific Gravity.	Weight of a cubic foot in lbs.
Water, Pure at 39·4° ...	1·000	62·425
,, Sea, ordinary ...	1·026	64·05
Clay	1·92	120
Sand	1·546	96·35
Gravel	1·8	112·6
Chalk	1·87—2·78	117 — 174
Shale	2·6	162
Marl	1·6 — 1·9	100 — 119
Slate	2·8 — 2·9	175 — 181
Limestone	2·7 — 2·8	169 — 175
Sandstone	2·3	144
Granite	2·63—2·76	164 — 172
Gypsum	2·3	143·6
Zinc, sheet	7·190	448·1
,, cast	6·861	427·6
Tin	7·291	454·4
Copper, sheet	8·785	547·5
,, cast	8·601	536·4
Bronze	8·4	524
Brass	8·393	523·1
Lead	11·352	707·5
Cast Iron	7·2	450
Wrought Iron	7·6	480
Steel	7·8	490
Fir	·48	30
Pitch Pine	·631	39·43
Oak, European	·69 — ·99	43 — 62
,, American	·87	54
Elm	·588	36·65
Mahogany, Honduras ...	·560	34·9
,, Cuba ...	·85	53
Teak, Indian	·66 — ·88	41 — 55
,, African	·91	61
Glass, Crown	2·5	156
,, Flint	3·0	187
,, Plate	2·7	169

Six and a quarter gallons of water = 1 cubic foot at normal temperature and pressure.

CHAPTER II.

FOUNDATIONS.

Definition.—The bases of walls, piers, columns, etc., directly supported or kept in equilibrium by the earth, are known as the foundations.

Necessity for Foundations.—Walls of buildings resting on ground of variable strength often fracture, due to the unequal settlement of the work. To prevent failure in this manner, the base of the walls of the building may be extended and supported by suitable foundations.

The object of foundations is to prevent inequality of settlement, and distribute the weight of the structure equally over the substratum.

The bases of structures are invariably made wider than the superincumbent mass to increase the stability and to counteract all the following damaging forces that tend to cause failure.

Damaging Forces.—The principal causes of failure are those which induce settlement, such as inequalities of earth resistance; the compressibility of mortar joints; lateral escape of soft soil; sliding of the substratum on sloping ground; the withdrawal of water; distributed lateral pressures, causing overturn, such as wind pressure, and thrust of barrel vaulting or of an untied couple raftered roof; concentrated lateral pressure which induces settlement and overturn, such as the thrust of framed floors, trussed roofs and

groined vaults subjecting small areas of support to great pressures.

Inequality of Settlement.—Inequality of settlement in buildings takes place from two causes—(1) the compressibility of the mortar joints; (2) the compressibility of the soil.

An allowance of 1 inch in 24 feet of brickwork in lime mortar is often provided for settlement, as in the example of the extremities of bridging joists of floors, at one end being supported by a brick wall, and the other extremities by iron columns, etc.

Nearly all soils, with the exception of solid rock and gravel, are compressible under pressures often attained in buildings. It is therefore impossible, where large buildings are erected on most soils, to avoid settlement; and the fact of any building settling is of no great import, provided the settlement be uniform and of no great depth, and the relative position of the parts of the structure unaltered. But where the resistance of the soil of every part of the site is not uniform, there is a risk of the above defect occurring, and special precautions must be taken to distribute the pressure to suit the varying strengths of the substratum.

Lateral Escape.—Heavy structures erected upon soft soils, such as running sands and peat, squeeze out from beneath the foundation, unless means are taken to confine the soil to the required area; this is usually accomplished by sheet piling, as described later.

Sliding.—This is a defect usually occurring where the building is erected on the slope of a hill, and the strata inclined, being depressed in the direction and towards the bottom of the slope. The weight of the building is liable to cause the strata to become detached and slide. This is prevented in two ways—(1) by driving piles at intervals to a considerable depth, thus connecting the strata: this

method is often objectionable, tending as it does to shake and disturb the soil; (2) by building a retaining wall; this is the better method, as it not only supports, but also protects the strata from the effects of the atmosphere, which in soils easily affected by the latter is a desideratum.

Withdrawal of Water from Foundation Earth.—Edifices built on damp soil, such as a sand overlying a clay, have their stability endangered should the water be drained away after the building has been erected, as it will cause the foundation earth to occupy a less volume and in the sinking will tend to fracture or overturn the walls; therefore the depth of the concrete foundation must be arranged below any probable adjacent cutting.

Distributed overturning Pressures.—Distributed forces acting upon the upper level of walls, such as the continuous pressure of barrel vaulting and the spreading tendencies of untied couple raftered roofs, and also the distributed pressures on wall faces, such as wind pressure, tend to cause failure in two ways—(1) by overturning, the minimum resistance being generally at the change of section usually at the ground level; (2) by subjecting the leeward edge of the wall to the pressure sufficient to crush the material or by throwing the weight on a small area of the substratum, forcing it from its original position and causing a settlement.

The stability of walls when subjected to such distributed overturning pressures is treated in the chapter on that subject.

Concentrated Lateral Pressure.—The thrust caused by untied principals or groined vaults or other forces acting at a point or along vertical lines on the wall are often resisted by buttresses.

Atmospheric Action.—Many otherwise thoroughly reliable

soils are practically reduced to the condition of mud if exposed to the effects of the atmosphere or to rain-water. The variation in temperature at the different seasons also causes the ground to expand and contract considerably.

Where foundations are constructed in such soils, they must be taken sufficiently deep to be beyond the effects of the atmosphere, that is below the line of saturation. Four feet below the ground level is usually sufficient for this purpose, the soil below this not being affected to any appreciable extent by the percolation and subsequent freezing of rain-water.

The line of saturation in the section of any part of the earth's crust represents the depth to which the soil at that part is saturated by the absorption of rain-water, and affected by atmospheric changes.

Preliminaries to Building.—The following conditions should be complied with :—(1) the requirements of the building owner; (2) the requirements of the local authorities; (3) the rights of adjoining owners must not be infringed; (4) plans and working drawings for the execution of the work.

First, the site must be surveyed and the levels taken, and the exact position of site as outlined on the deeds must be confirmed, to avoid subsequent disputes with adjoining owners of land, as it is a frequent cause of litigation in urban districts where the sites are so often covered over to their boundaries. Plans of the proposed building are drawn up to meet the requirements of the building owner. Drawings of all proposed work must be submitted to the local authorities for their approval. These comprise complete plans, sections and elevations not less than $\frac{1}{96}$ full size. (2) Plans, showing drainage. (3) Block plan showing position of building with respect to surrounding property. The practice in London and most other places varies in respect of payment of the public surveyor's fees. In London there is a definite scale of

charges for this purpose. When the above are satisfactorily settled, contract drawings for the proposed works are prepared. If of a justifiable magnitude, and the work is to be competed for, a bill of quantities should be prepared, copies of which are supplied to the various contractors as a basis for tendering; all other conditions being equal, the lowest should obtain the contract if the work is carried out. For the various conditions affecting a building contract, reference should be made to the form of building contracts issued by the Royal Institute of British Architects, which document contains a series of clauses usually required to be agreed upon. If not relevant to the particular work, any of these may be deleted.

In the planning of a building great care must be taken that no excavation withdraws the lateral support to the ground of adjoining owner, and if the latter has had a building erected for twenty years without protest and has thus acquired prescriptive rights to lateral support, then any damage ensuing from excavation at any time will have to be made good; also the new building must not obstruct any unreasonable amount of light. Adjoining owners may have obtained prescriptive rights by a twenty years uninterrupted enjoyment. What constitutes an actionable obstruction of light is a debatable quantity, but an unobstructed angle of 45° is invariably non-actionable.

Excavations.—Before commencing any constructional work in connection with a building it is necessary as the first operation to carefully take the levels of the site, in order first to arrive at an estimate of the amount of earthwork to be done; and secondly, to determine the design of the basement storey, this latter often being materially affected if the differences in level of the various parts of the site are great. The next operation is to level the ground. This in most instances consists in excavating and removing earth from one

part of the site and depositing in other parts to form embankments, or to fill up hollow places. In order to conduct these operations in the most economical manner the levels must in all instances be taken and plotted with the greatest accuracy. This can only be efficiently done on areas of any magnitude by means of the surveyor's level, the method of employing which will be described later. The method of employing the ordinary mechanic's level is given in the Elementary Course. All levelling operations for ordinary constructional work may be carried out by referring them to the principles laid down for performing the three following operations :—

1. Taking levels of site.

2. Levelling the bottoms of trenches for drains or foundations.

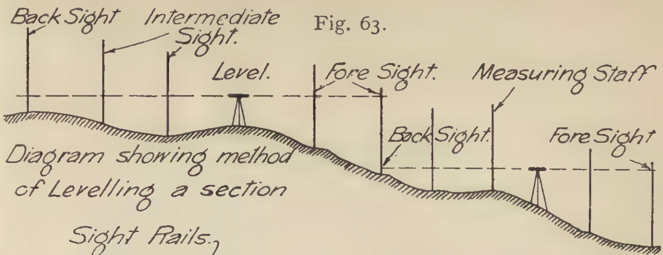
3. Embanking for roads or levelling of depressions.

Instruments.—The instruments required to determine the levels of the site are—first, the surveyor's level; secondly, the measuring staff; thirdly, ranging poles; and chains, tapes or wood rods, the latter being the most accurate instrument for ordinary purposes for measuring or setting out lineal dimensions.

Methods of Levelling.—Taking the levels of a site may be carried out in one of three ways—first, by taking a number of section lines across the site; secondly, by erecting the level in a commanding position and taking the relative heights of the salient points and noting same on plan (this method is only applicable for small sites); thirdly, by contours.

In all three methods it is necessary to have a datum level to commence from, and from which all other levels can be referred. A line on some permanent structure in the immediate vicinity is usually taken, or if such does not exist, a stout stake is driven in the ground in a position away from the work where it is not likely to be disturbed.

Fig. 63.



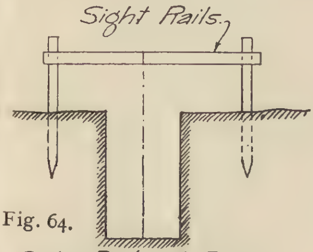


Fig. 64.

Sight Rail with Posts fixed in ground.

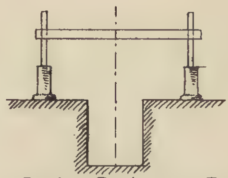
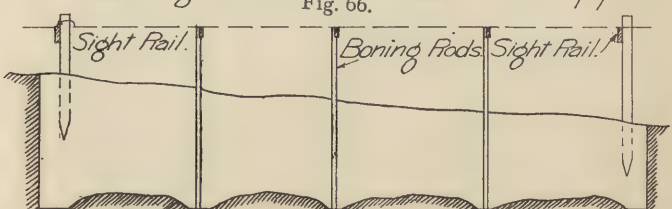


Fig. 65.

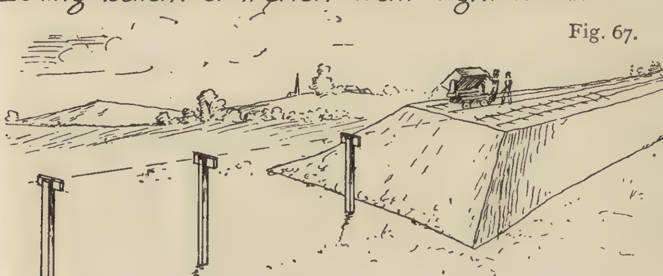
Sight Rail with Posts fixed in drain pipes

Fig. 66.



Boning bottom of Trench from Sight Rails.

Fig. 67.



Boning Rods fixed indicating level for top of embankment

First Method.—A number of sections are ranged across the site, each line being numbered or lettered; the level is then set up, on or in close proximity to the first line and the datum; the measuring staff is then held by an assistant on the datum point and then on the extremity of the line, the relative heights of the two points being recorded in a field book kept for that purpose. A number of points on the line are then taken, and the measuring staff is held over them, and their relative heights are recorded, and their distances from the beginning of the line are measured. When the bottom of the measuring staff rises above, or its top becomes depressed below the line of sight, through the rise or depression of the ground, the level must be moved further along the line and the preceding operations repeated. Figure 63 illustrates the method. The following is a form of field-book with the readings for a section entered:—

FIELD LEVEL BOOK.

Back Sight.	Inter. Sight.	Fore-Sight.	Rise.	Fall.	Reduced Levels.	Dis-tance.	Total Dis-tance.	Remarks.
						chains		
4·15	...	...	...	...	100·0	...	...	Bench Mark A
	4·13	...	·02	...	100·02	1	...	1 peg
	5·01	...	...	·88	99·14	2	...	2
	4·86	...	·15	...	99·29	3	...	3
	6·06	...	...	1·20	98·09	4	...	4
		8·02	...	1·96	96·13	5	...	5
12·25								
	8·46	...	3·79	...	99·92	6	...	6
	3·04	...	5·42	...	105·34	7	...	7
		2·15	·89	...	106·23	7·57	...	Bench Mark B
12·60								
	7·19	...	5·41	...	111·64	8·57	...	8
		2·53	4·66	...	116·30	9·57	...	9
9·37								
	5·75	...	3·62	...	119·92	10·57	...	10
		3·94	1·81	...	121·73	11·57	11·57	Bench Mark C
			25·77	4·04	21·73			
			4·04					
			21·73					

The above shows a typical field level book. The reduced level of the first point is taken as 100 feet above a datum level; the levels are all read in feet and hundredths of a foot; the distances are taken in chains and links, but may be taken in feet and inches. The rise and fall columns should be balanced, also the first and last reading in the reduced levels; these two quantities will equal each other if the computations have been correctly made.

Second Method.—The second method is similar to the first, but the readings of all the sections are taken from one setting up of the level. All other is evident from the previous explanation.

Third Method.—The method of contouring is the most useful, but takes the longest time to perform; it consists in describing upon a plan a series of level lines with a uniform vertical interval between them. To carry out this operation it is usual to erect the instrument on the highest point of any section of the area to be contoured, and from this point to range a number of radiating lines, their direction being fixed by taking their bearings. The height of the instrument is then taken, and the man with the measuring staff is directed up or down each line in succession until a number of points of the required vertical interval and their distances from the initial point are determined. This method is most useful for laying out large estates where extensive works are projected, as on such a plan the problems of drainage and roads of convenient and economical gradients can easily be laid down.

When the levels of a site are known, and the building is planned, and the position of one of its leading lines is determined, to set out the remaining lines of an ordinary building becomes a simple matter, only requiring great care in the measurements of the parts. If the setting out is rendered difficult through differences of level in the parts, a theodolite would very much simplify the operations.

Trenching.—When the lines of the building have been laid down and all its salient angles pegged out, the work of excavating the trenches commences. It is absolutely necessary that the trenches should be level along their bottoms. To ensure this two or more sight rails (as shown in figures 64 and 65) are erected over the trench; it is necessary that the side posts of these should be fixed in such a position that they shall not be disturbed by any of the subsequent operations. A level line is sighted through the level and marked on the sight rails; the cross bar is then fixed on each, and a mark is made on the bars plumb over the centre of the trench. The width of the trench is marked out with the line and pegs (page 86, Elementary Book), and the excavation is carried on, timbering being inserted as the earth is removed if required, by one of the methods afterwards described. When the full depth of the trench has been nearly reached, a number of points are sunk to the exact depth by means of boning rods, the top of which is sighted between two of the sight rails, as shown in figure 66. The remaining parts of the trench bottom are then taken out level between the points so determined. A similar process is employed for sinking a trench for a drain, the difference being that the sight rails have a difference in height necessary to give the required fall.

3. *Embanking.*—The method of forming an embankment is as follows:—The centre line of the proposed work is ranged out on the ground, and at equal intervals along the line boning rods are erected, the two extreme rods being first fixed either level or with a difference in height sufficient to give the required gradient; a rod is then erected on each of the intervals determined upon, and boned between the two extreme rods. The embankment is then commenced from one end, the earth being tipped in from carts or waggons until the tops of the boning rods are reached. Sufficient

earth in excess must be allowed to compensate for compression and settlement. The width of the embankment is completed as the work is pushed forward, as shown in figure 67.

Timbering for Excavations.—It becomes necessary, where earth has to be excavated to any considerable depth, for foundations or other purposes, to support the sides of the cutting until the sinkings or trenches are filled in, or other action taken to permanently support the sides. This end is attained by means of timber shores, the arrangement of which is modified and governed by several conditions, such as the nature of the soil, the size of the cutting, and the special peculiarities of the particular piece of work under consideration.

There are three typical methods of strutting used for supporting the sides of narrow trenches excavated for foundations or drainage work, shown in figures 68 to 70.

The first, used for firm ground, consists of short upright members, termed poling boards, out of 9 in. × $1\frac{1}{2}$ in. usually from 3 to 8 feet long, placed in position in pairs, one board on each side of cutting; these are kept apart by struts out of about 4 in. × 4 in., or short ends of scaffold poles cut and driven tightly between the poling boards. The strutting is fixed as soon as the trench has been made sufficiently deep. The horizontal distance apart between the adjacent systems of strutting varies according to the cohesive strength of the soil, but never less than 6 feet, which is just sufficient to allow a man to work in with effect.

The method shown in figure 69 is adopted where the earth requires to be supported at shorter intervals than six feet, and consists of upright poling boards and struts as before, but with the addition of a horizontal timber termed a waling piece. The process of fixing is as follows:—The cutting is made, commencing at one end, and as soon as

sufficient earth has been excavated a pair of poling boards and struts is inserted as in the first method; this process is

Fig. 68.

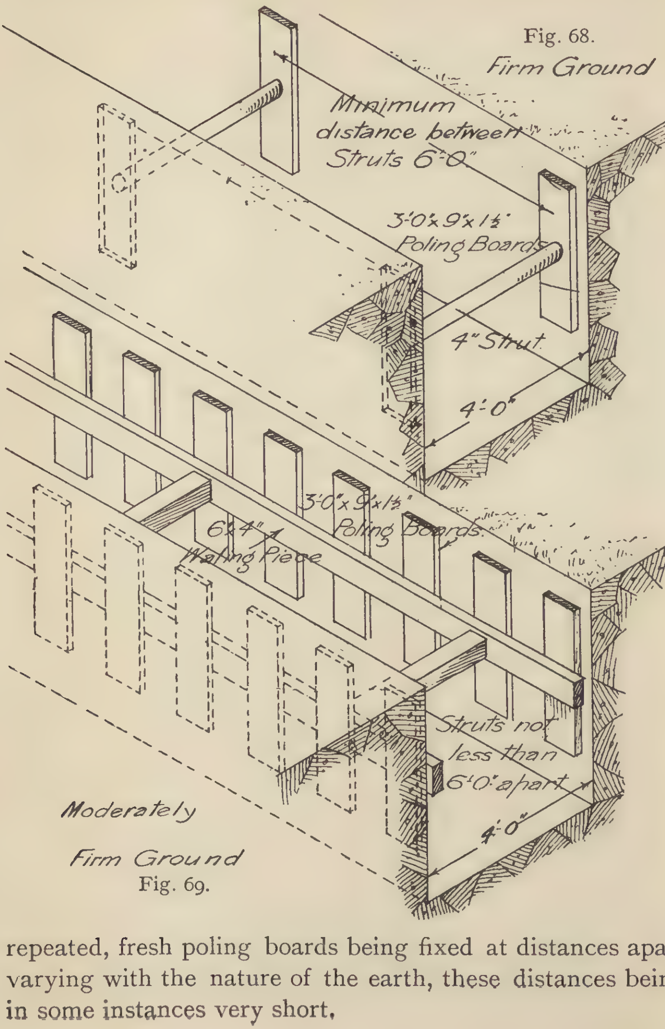


Fig. 69.

repeated, fresh poling boards being fixed at distances apart varying with the nature of the earth, these distances being in some instances very short.

Horizontal members, 4 in. × 4 in. or upwards, are placed one on each side of cutting and strutted tightly against the poling boards. After about 12 feet has been thus cleared, the struts which were fixed first are then knocked out; a fresh depth is commenced, and treated in a similar way.

The third method is employed where the earth is very soft, and consists in laying horizontally boards usually 9 in. × $1\frac{1}{2}$ in. against the sides of the excavation; the boarding laid in this manner is termed sheeting, which is supported by upright poling boards and struts, as shown in figure 70. The method of fixing is as follows:—The earth is taken out to a depth of 9 inches, and a pair of boards are inserted and strutted apart; another depth of 9 inches is then taken out, and sheeting fixed as before. This process is repeated until a sufficient number of boards have been inserted, usually four; upright poling boards are then placed in position against the sheeting and strutted apart, as shown in figures 70 and 71; the first fixed struts are now struck and cleared away.

The above system may be improved upon, when the depth of the cutting is not too great, by cutting the sides of the excavation to a slight batter, as shown in figure 71; by so doing, the timbers are prevented from falling should the earth contract on becoming drained; it also facilitates the fixing of the struts.

Large Cuttings.—Continuous trenches, if made in bad ground, are generally arranged as shown in figure 72.

At intervals guide piles are driven in, to which walings are bolted, and sheeting consisting of boards about 10 feet long, shod with iron, termed runners, inserted between; these are driven a short distance into the ground, the earth between the two systems of piles being then taken out, and care taken not to excavate within a foot of the bottom end of the runners, which are again driven in and the process

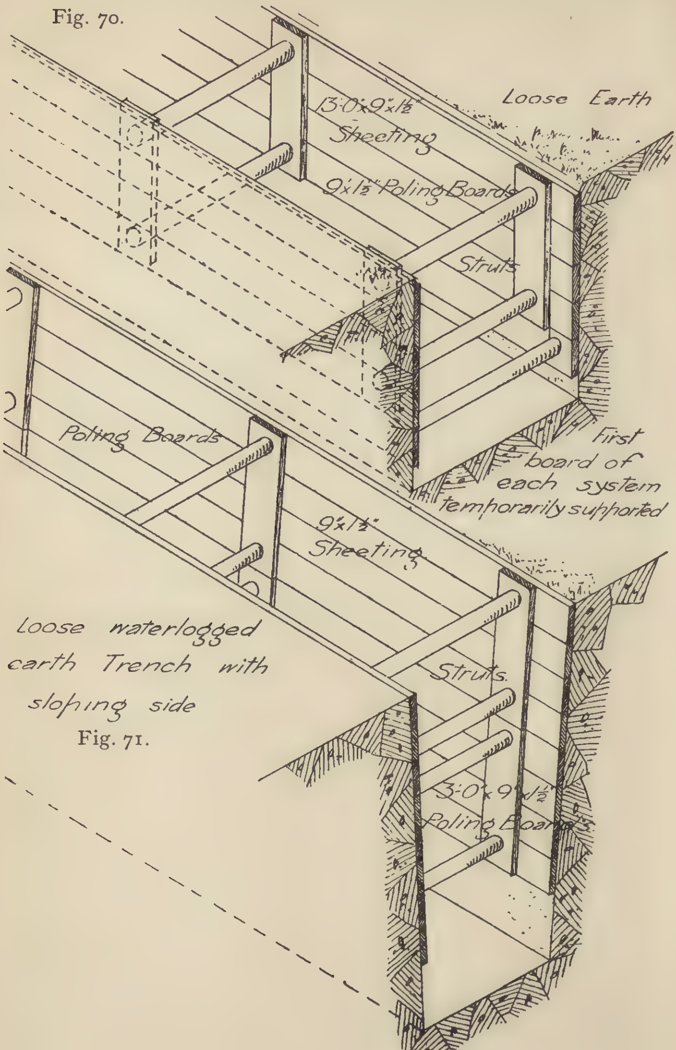

Loose Earth
13'·0"×9"×1½" Sheeting
9"×1½" Poling Boards
Struts
First board of each system temporarily supported
Poling Boards
9"×1½" Sheeting
Struts.
3'·0"×9"×1½" Poling Boards
Loose waterlogged earth Trench with sloping side

Fig. 70.

Fig. 71.

repeated. After the excavation of the first part, wales, consisting of whole timbers, are placed in position and strutted apart, the struts being also of balk timber. Long struts are supported in the direction of their length by

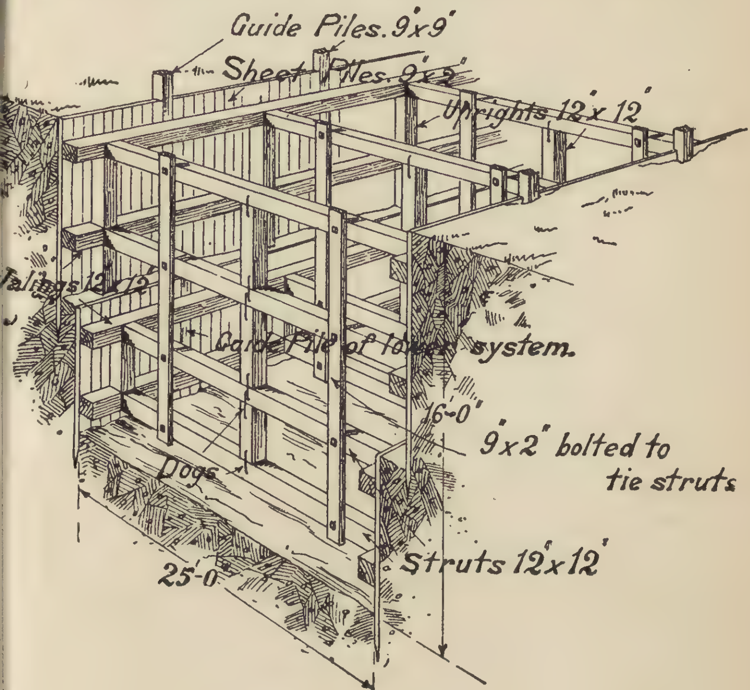


Fig. 72.

short uprights secured to them by dogs. Uprights are also placed between the waling pieces as each fresh one is inserted.

After the ground has been excavated to the depth of the runners, a fresh system of piles and runners is driven slightly in advance of the former system, and the ground excavated as before. Cuttings are made in firm ground

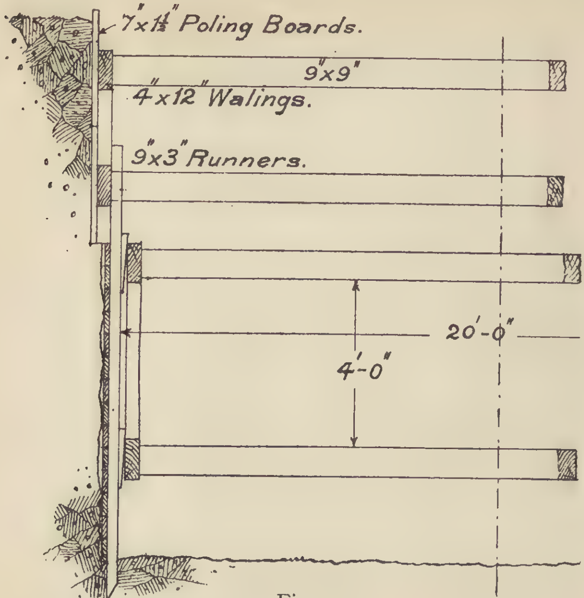

7"x1½" Poling Boards.
9"x9"
4"x12" Walings.
9"x3" Runners.
20'-0"
4'-0"

Fig. 73.

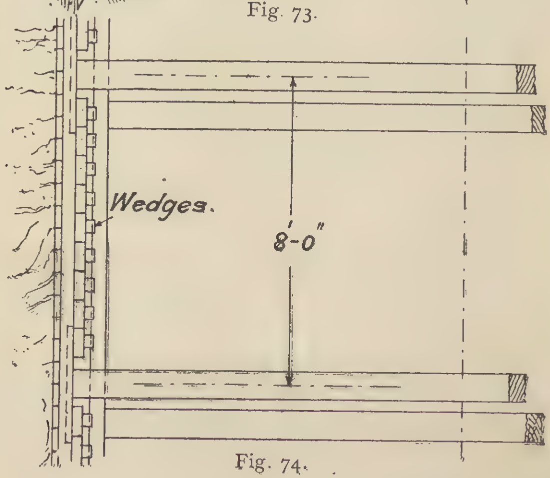

Wedges.
8'-0"

Fig. 74.

by excavating the earth and using ordinary sheeting, but if the cuttings are required to exceed 30 feet in width, it is found to be more economical to adopt a system of raking shores.

The method illustrated in figures 73 to 75, where the ground is soft and waterlogged, is especially suitable for

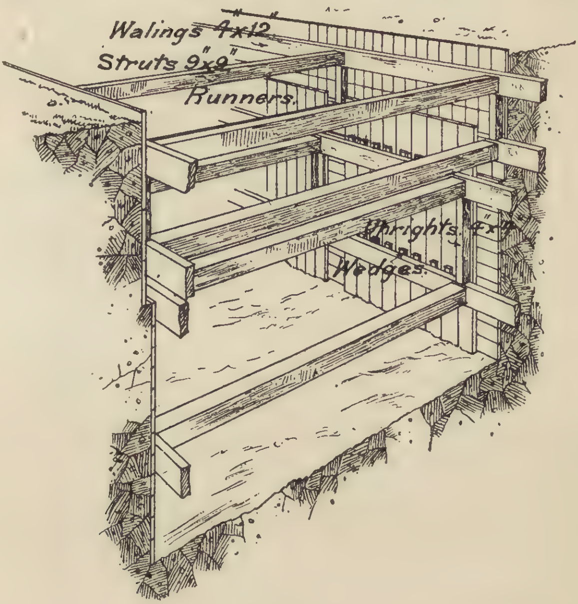


Fig. 75.

running sand. By this method as much of the earth is taken out as is possible without the sides of the excavation falling in, generally from 4 to 6 feet ; this is then supported by upright sheeting, waled and strutted. The excavation is continued by lining the cutting with a secondary system of runners, *i.e.*, battens, 7 in. × 2 in., pointed at lower ends, and of about 9 feet in length. These are waled and strutted ; between each runner and waling piece a wedge is inserted.

The method of proceeding with the excavation is as follows: The wedges securing one runner are loosened, the earth from the foot removed to a depth of about 12 inches, the runner being dropped as the ground is removed and re-wedged. Each runner is successively treated in this manner till the whole system has been lowered the necessary amount. It is essential that the feet of these runners should be at all times kept in the ground, as if any portion of the vertical side of the excavation be exposed the earth is liable to ooze out and leave the back of the runners unsupported, and cause the whole system to collapse.

Sinking Shafts.—It is often necessary to sink shafts for foundations, etc. These are made from 4 feet square and upwards, the former being the smallest size a man can work in without difficulty.

Shafts from 4 to 9 feet square are timbered as shown in figures 76 to 78.

In ordinary soils the earth is excavated to a depth of at least 3 feet, and in firm soils 6 feet. The sides of the excavation are then lined with vertical sheeting, consisting of boards 9 inches wide, 1 in. to $1\frac{1}{2}$ in. thick, strutted apart by frames of horizontal waling timbers, a pair of which are placed in position against two opposite sides, and strutted apart by another pair driven tightly between and against the remaining sides, these being secured by cleats nailed to the fixed waling pieces. Another depth of earth is then taken out, and a second system of sheeting placed in, the upper ends of which lap about 1 foot over the lower ends of the first system of sheeting; another frame is placed in position as before, securing both systems of sheeting. Uprights are fixed in the angles between the waling pieces, and often at intermediate positions along their length. This process is repeated till the required depth is obtained.

The timbering requires to be supported if the depth be great, to prevent it from sliding down on the

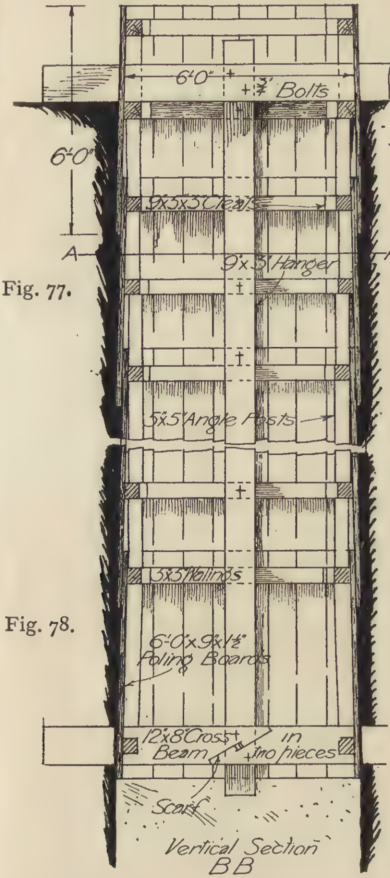


Fig. 77.

Fig. 78.

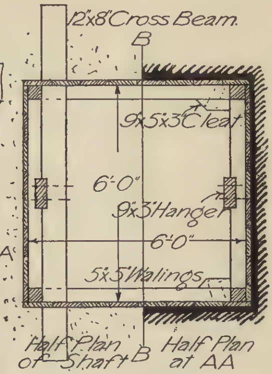


Fig. 76.

removal of the earth from its lower end. Where this has to be done, the upper end of the shaft is left projecting about 3 feet above the ground level. The two first

fixed waling timbers at the ground level are continued through the shaft, and project several feet on either side of it, a good bearing on the solid ground on both sides of the shaft being thus obtained, as shown in figure 77.

These members are usually out of balk timbers; they are strutted apart as described. An upright vertical timber is notched over this, and spiked to the face of the waling timbers below, the whole being thus tied together.

These are often supplemented by similar timbers at the bottom of the shaft. These timbers are fixed in two pieces, with a scarf in the centre; they project about 3 feet into the side of the pit on either side, as shown in figure 78. A chain is sometimes employed in addition to the timber spiked to the walings.

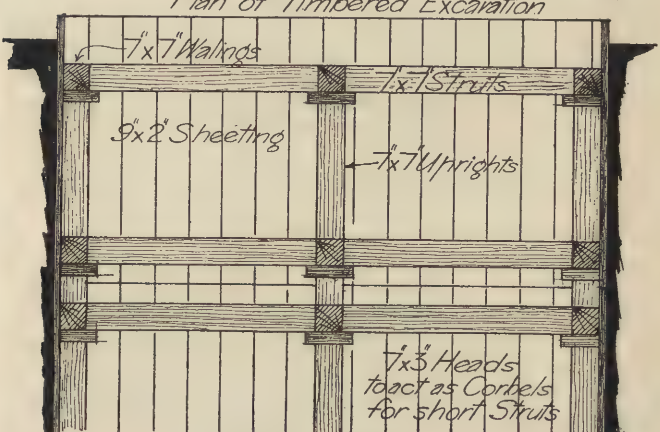
Intermediate struts are required to support the horizontal walings where the size of the pit is above 9 feet square. One system of struts is fixed between two opposite sides, being supported at their ends by cleats, as shown in figures 79 and 80, these being necessary to prevent the timbers falling should they become loose during the progress of the works. The struts that support the remaining sides intersect by butting against the first system, as shown in figure 80, and are therefore fixed in two pieces. The struts at their intersection are supported by uprights, on the upper ends of which short ends of timber are placed, projecting beyond the sides, acting as corbels, and forming a ledge upon which the shorter struts take a bearing, as shown in figure 80.

The earth is raised from the bottom of the shaft, if of a great depth, by means of hoisting tackle; but if the cutting be shallow, stages are often erected in 6 feet heights, the earth being shovelled from one to the other till the top is reached.

Tunnelling.—In building operations it is often necessary

Fig. 79

Plan of Timbered Excavation

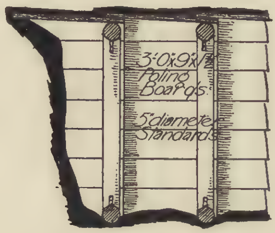


Vertical Section

Fig. 80.

to bore a tunnel in order to construct drains, etc., the process being carried out as follows:—

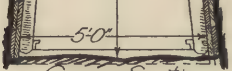
Tunnels are made just large enough for a man to work in, that is from 4 to 7 feet square. The earth is taken out in sections of about 3 feet at a time, poling boards of the same length being then placed against the upper surface, and kept in their position by a system of strutting, consisting of a head, sill, and two uprights, out of either round or



Section

Fig. 81.

square timbers. The sill is placed in position first, being partly bedded in ground to prevent lateral motion, and being bedded in its correct vertical position by boning through from the sills previously bedded; the head next, then the



Cross Section

Fig. 82.

struts, which are cut and driven tightly between the two. The next section is then cleared out, commencing at the top, just enough being taken out there to allow of the next

system of poling boards being inserted, these being arranged to overlap the first system at their back end, the two being then strutted up together; this process is repeated till the tunnel is finished.

If the soil be bad and the sides liable to fall in, they must also be lined by poling boards, these being kept in their place by the uprights.

Large spikes, similar in shape to floor brads, are driven into the head and sill, with their heads left projecting so as to be easily withdrawn, to secure the struts when in position. Wood cleats are often used in place of these.

These tunnels are usually made slightly tapering from the base to the head, as shown in figures 81 and 82.

Foundations.—The construction of foundations varies with the nature and bearing strength of the soil. The following are the ordinary soils met with in practice and the method of treating them:—Rock, chalk, gravel, clay, and sand.

Rock.—Foundations laid upon the solid rock are undoubtedly secure, as far as settlement is concerned, such a substratum being practically incompressible. Rocks often have fissures and defective parts, and all gaps must be filled up with concrete, any unsound parts being cut away. Rock foundations are very expensive in working, owing to the extra labour involved in cutting them; but where they occur they may be built upon direct.

Chalk.—Chalk varies considerably in hardness, being in a dry or well-drained position very hard; but if subject to much wet it becomes saturated and thus rendered soft.

The site for buildings on chalk soils should be drained, and precautions taken to prevent them becoming wet. Where this can be done, the structure can be built

upon the chalk direct, after it has been levelled; but where heavy buildings are erected, or great weights concentrated, concrete should be employed to distribute the pressure.

Gravel.—Where lateral movement is not likely to occur, gravel is one of the best soils to build upon; it is not affected by the action of the atmosphere, and is practically incompressible.

Clay.—Clay is a good soil to build upon where the foundations are taken deep enough to be beyond the action of the atmosphere. Clay is very subject to expansion and contraction with the variations in temperature and is therefore dangerous to build upon unless protected.

Sand.—Sand is a good material to build upon, if it can be kept dry and confined laterally; if subjected to the effects of running water it is liable to be scoured from about the foundation.

In all the above soils, with the exception of the rock, and the chalk when in a good condition, it is usual to form a bed of concrete, the area of which is proportioned to the weight to be carried and the bearing strength of the soil.

The following are cases that require special treatment:—(1) Soft soils of a great depth; (2) soft soils with hard strata beneath; (3) soils not having a uniform resistance, formed of rocks which have hollows or fissures filled up with some softer material.

1. Foundations in the first case may be made in one of two ways, or by a combination of both—(1) by sheet piling; (2) by forming the foundation on planks.

(1) *Sheet Piling.*—Sheet piling, as shown in figure 83, is used to prevent the lateral escape of the soft soil. It consists of flat timbers, about 9 in. to 11 in. × 3 in., driven in and

Fig. 83.

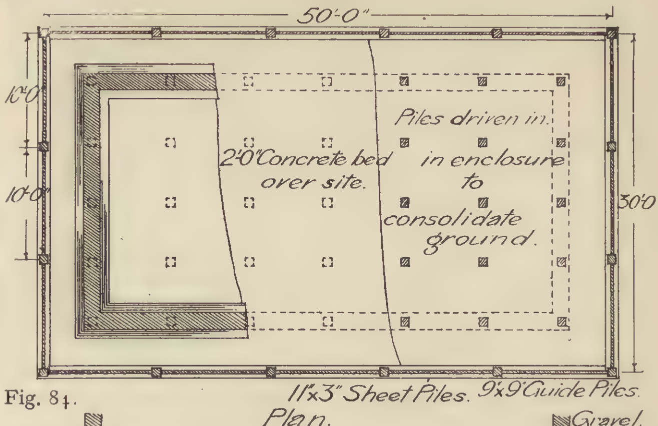


Fig. 84.

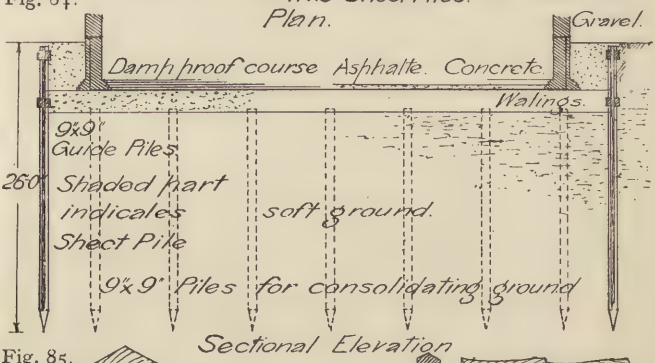
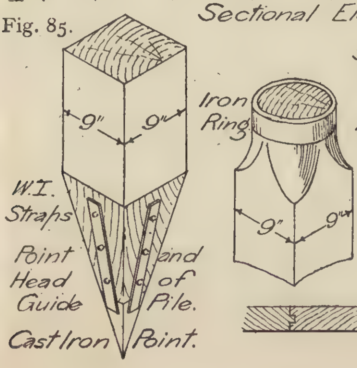


Fig. 85.



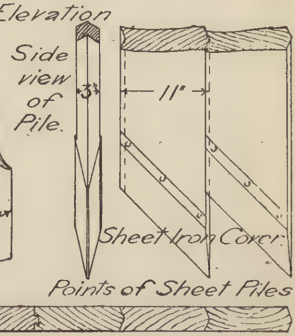


Fig. 86.

enclosing the site to be built upon, the area of the latter being sufficient to withstand the pressure brought to bear upon it; as the soil cannot escape, it must necessarily remain and support the structure. If the site is to be drained it must be done before the building is erected.

In order to enclose a site with sheet piling, it is necessary to drive guide piles into the soil, at intervals of from 6 feet to 10 feet apart. These usually consist of timbers 9 inches square and upwards, pointed and shod with iron at the lower extremities, as shown in figure 85. The point consists of a pyramidal block of cast iron, about 6 inches in length, and having a base about 4 inches to 5 inches square; this has four mortices, about 2 in. × $\frac{1}{2}$ in. by about $\frac{3}{4}$ inch in depth. This is placed on the end of the pile, which has been cut as a truncated pyramid, the iron block completing the latter, and is fixed with four straps of wrought iron about 1 foot 6 inches in length, with the ends turned to fit in the mortices of the cast-iron points. The straps are fixed to the wood pile with large clout nails, the point being thus fixed, as shown in figure 85. The guide piles are driven in to within about 2 feet of the ground; they are connected together by horizontal timbers about 9 in. × 6 in., bolted to them in pairs, with a space between equal to the thickness of the sheet piles. Two pairs of waling pieces are thus fixed, one at the ground level, and the other near the top of the piles in the spaces; between these the sheet piles are driven, the walings serving to keep them in an upright position. The joints of the sheet piles are prepared in three general ways: square, grooved and tongued, or bird's-mouthed together, the first and last being those most commonly used, the second and third being shown in figure 86. The sheeting piles are pointed at their lower ends, in the way shown in figure 86, to cause them to draw in one direction; they have a piece of sheet iron nailed over the end to protect the point.

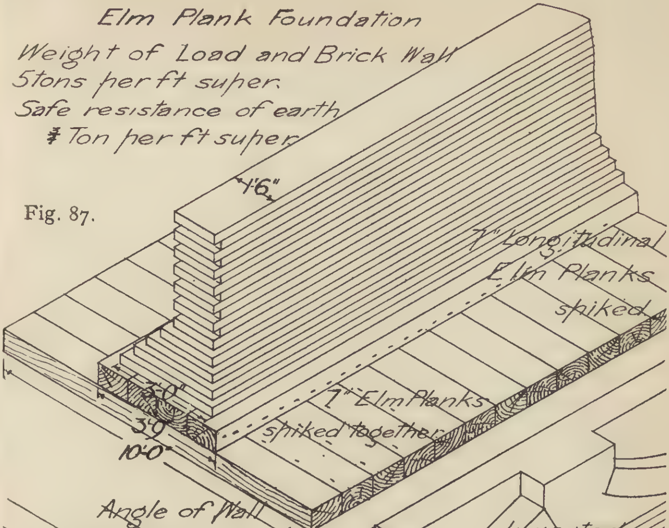

Elm Plank Foundation
Weight of Load and Brick Wall
5tons per ft super.
Safe resistance of earth
¾ Ton per ft super
1'6"
7" Longitudinal
Elm Planks
spiked
3'0"
3'9"
10'0"
1" Elm Planks
spiked together

Fig. 87.

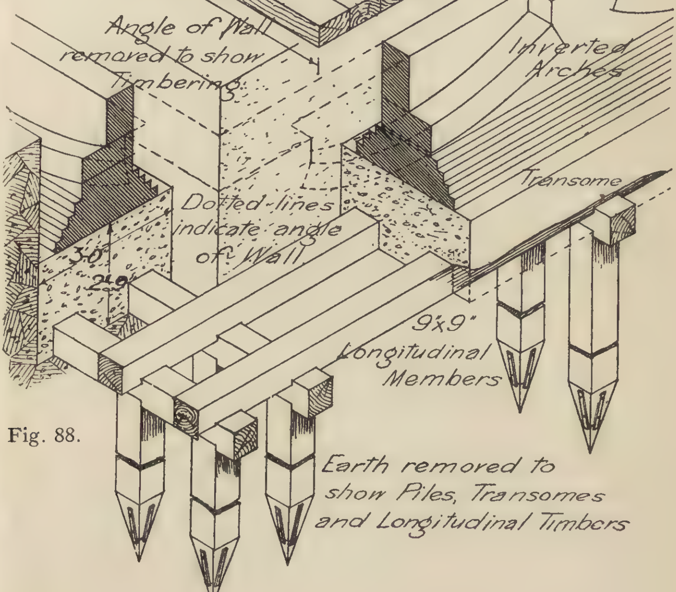

Angle of Wall
removed to show
Timbering
Inverted
Arches
Transome
Dotted lines
indicate angle
of Wall
3'0"
2'9"
9"x9"
Longitudinal
Members
Earth removed to
show Piles, Transomes
and Longitudinal Timbers

Fig. 88.

The ground within the enclosure is frequently consolidated by driving in piles, as shown in figure 83, the tops of these being covered by a layer of concrete, covering the whole site within the enclosed area.

The enclosed site below the level of the piles is often removed for a few feet in depth, and replaced by a layer of drier material. The foundations are formed by a wide layer of concrete, or by timber platforms.

Ferro-Concrete Piles.—Of late years guide and sheet piles have been most successfully made of ferro-concrete, and this construction is now rapidly displacing the use of timber for piles. These when properly constructed are imperishable. They are of concrete reinforced with steel rods, the latter giving to these piles sufficient tenacity to resist fracture induced by the blows of the pile driver. A further description of these is given in the article on ferro-concrete.

(2) *Plank Foundations.*—These are useful in soft and very wet soils. Each may consist of a platform of timber formed by two layers of planking, as shown in figure 87, the lowermost layer being placed at right angles to the length of the wall; the uppermost parallel to the length of the wall, and being spiked to the first; on this the brickwork or masonry footings are commenced. The best and most plentiful wood in England for this purpose is elm, which if kept constantly wet is practically imperishable, but where exposed to alternations of wetness and dryness will rapidly decay. Timbers for this purpose should be treated to one of the preservative processes mentioned in the article on Timber, notably creosoting.

Example: Let it be required to support a wall 2 bricks in thickness and stressed with a load of 5 tons per superficial foot by a plank foundation, the safe resistance of the soil being $\frac{3}{4}$ ton per superficial foot. Determine width of foundation and thickness of planking required.

Taking a length of 1 foot—

$$\therefore \text{ width of foundation} = \frac{\text{total load}}{\text{safe resistance of earth}}$$

$$\text{,,} \qquad \text{,,} \qquad = \frac{5 \times 1\frac{1}{2}}{\frac{3}{4}}$$

$$\text{,,} \qquad \text{,,} \qquad = 10 \text{ feet.}$$

The length of the transverse planks forming the foundation are first laid: then longitudinal planks, in this case, say, to a width of 3 feet 9 inches, are laid on and securely spiked

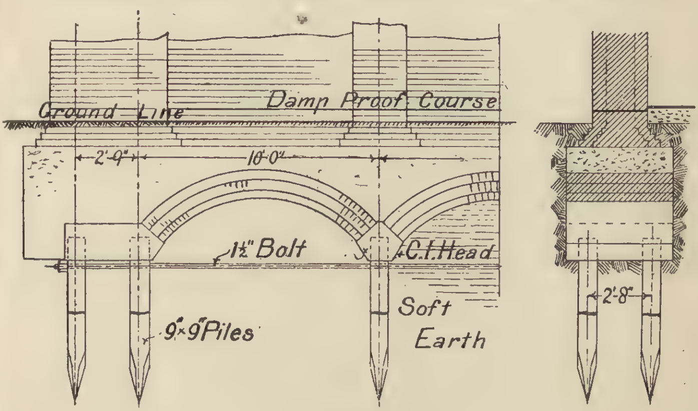


Fig. 89.

to the transverse; upon this the footings commencing with a width of 3 feet are bedded. Treating the projecting planking as cantilevers, the lengths of which may be taken as 44 inches, the thickness may be determined as follows, the coefficient of rupture for elm C = 63 cwts., and for safety let a factor of 5 be taken :—

$$\text{M L} = \text{M R}$$

$$\frac{w\, l^2}{2} = \frac{C\, b\, d^2}{6 \times 5}$$

$$w = \frac{\frac{3}{4}}{12} \text{ tons per inch} = \tfrac{3}{48} \text{ tons per inch} = \tfrac{15}{12} \text{ cwts. per inch.}$$

$$\text{Then} \qquad \frac{15 \times 44^2}{12 \times 2} = \frac{63 \times 12 \times d^2}{6 \times 5}$$

$$d = \sqrt{\frac{3025}{63}}$$

$$d = 7 \text{ inches nearly,}$$

as shown in figure 87.

2. *Soft Soils with Hard Strata beneath.*—Cases of this description are commonly met with where buildings are erected on the banks of rivers; they are usually dealt with in one of two ways—(1) by piling, until the pile refuses to be driven ¼ of an inch at each blow. Figure 89 illustrates piles driven in soft ground, supporting cast-iron heads, brick relieving arches upholding concrete beam, forming the foundation. (2) By sinking piers down to the firm stratum.

(1) *Piling.*—The foundations are formed by driving piles from 9 inches square and upwards, similar to the guide piles mentioned, till their points rest on the solid ground. These are driven in to varying distances apart under all the piers of the building, which should be connected by inverted arches, as shown in figure 88, to distribute the pressure uniformly along the foundations, and the piles being bridged both transversely and longitudinally by horizontal timbers of about the same sectional area as the piles, the whole being arranged as shown in figure 88, which also illustrates the arrangement of the piles at the angle of the building. On the top of the timbering may be placed a platform of timber, or a layer of concrete, on which the walls are built.

Pile Driving.—Piles are driven in the ground usually by means of a ram, which is a block of iron, sometimes called a monkey, weighing from 5 to 30 cwts., raised by a crab winch, actuated by manual or steam power. Figure 90 is an illustration of a pile engine, capable of being worked by manual or by steam power. The monkey in these machines is raised to a given height, when, by an arrangement known as a slip-hook, it is released, and descends with a force increasing directly as the height to which it had been raised. This distance ranges from 5 to 10 feet, usually 5 feet, as a comparatively heavy monkey with a shorter fall is found practically to be better than a light monkey with a

great fall, the latter having the tendency to shiver the pile instead of forcing it downwards. Piles are considered to be sufficiently driven when the last blow does not sink the head more than $\frac{1}{4}$ inch.

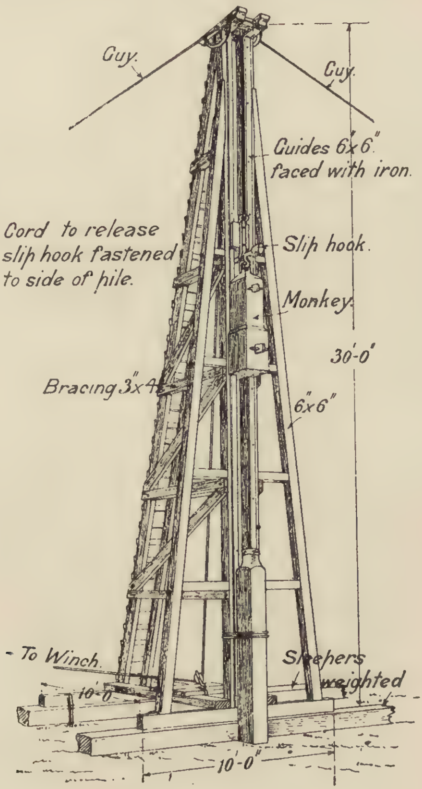


Fig 90.

The supporting power of a pile depends—(*a*) upon the resistance at the point to resist penetration ; (*b*) the friction of the earth upon the sides of the pile ; and (*c*), if projecting above the ground, its strength as a pillar.

The following empirical and well-known formula of Major Saunders, U.S. Eng., will give the safe load supported by piles in cwts. :—

Let d = the distance driven by last blow in inches
h = height fallen by monkey in inches
W = weight of monkey in cwts.

$$\text{then safe load in cwts.} = \frac{Wh}{8d}$$

EXAMPLE: Determine the supporting power of a pile, which at the last blow of a weight of 10 cwts. falling freely through the height of 10 feet is urged through the ground a distance of a quarter of an inch.

Then by the formula

$$S\,L = \frac{Wh}{8d}$$

$$S\,L = \frac{10 \times 120}{8 \times \frac{1}{4}}$$

$$S\,L = 600 \text{ cwts.}$$

that is, 30 tons can be safely carried by every such pile. It can be shown by the laws of falling bodies as given in the accepted works upon Mechanics that the factor of safety taken by Major Saunders is $\frac{1}{8}$th of the ultimate resistance, for

$$\text{Force or resistance} = \text{mass} \times \text{acceleration}$$

$$\therefore \quad R = m\,a$$

$$\text{but acceleration} = \text{velocity}^2 \div 2 \text{ space}$$

$$\therefore \quad R = \frac{M\,v^2}{2\,S}$$

but S is in this case the distance passed through by a body when arrested at its greatest velocity till it comes to rest

$$\text{but mass} = \text{weight} \div \text{gravity}$$

$$\therefore \quad R = \frac{W\,v^2}{2g\,S}$$

but $v^2 = 2g\,S$ and S here equals h or height passed through

by a falling body from its state of rest till the instant it strikes the pile

$$\therefore \quad R = \frac{W\,2gh}{2g\,S}$$

$$\text{that is} \quad R = \frac{Wh}{S}$$

but S in this case is the *d* of Major Saunders' formula, being the distance that the pile is urged by last blow

$$\therefore \quad R = \frac{Wh}{d} \qquad \text{Q. E. D.}$$

Small steam hammers are sometimes used as pile-driving machines. Rankine says that it appears from practical examples that the limits of the safe loads on piles are as follows:

1. In piles driven till they reach the firm ground, 1,000 lbs. per square inch of area of head.

2. In piles standing in soft ground, by friction, 200 lbs. per square inch of area of head.

Sinking Piers.—Piers of concrete or brick may be taken at intervals through the soft soil down to the hard substratum; these are connected by arches or girders, upon which the superstructure is raised. If the soil is sufficiently firm, timbered excavations are made, as shown in figures 76 and 77, and concrete or brick piers may be formed; but if the soil is waterlogged or in any way insecure, brick cylinders may be sunk, or iron cylinders or caissons as will be described later, these two cylinders being filled up with concrete and forming solid piers.

Concrete Piers.—The following example will illustrate concrete piers. Let a bed of soft soil 30 feet in depth overlie a compact gravel substratum with a safe resistance of 8 tons per super foot. It is required to erect a wall with a load of 8 tons per lineal foot. Let the distance between the centres of adjacent piers be 15 feet, then the total load supported by each pier equals 15 × 8 = 120 tons. Let the weight of concrete pier be taken as 40 tons, then the tota

load on bearing stratum equals 120 + 40 = 160 tons. The sectional area of concrete pier at base equals 160 ÷ 8 = 20 super feet. Let the horizontal dimensions of pier to suit brickwork be taken as 5 ft. 6 ins. × 4 ft. A timbered excavation having these internal dimensions is prepared, and then filled solid with concrete, the timbering being removed as the concrete is deposited, or if the ground is uncertain the timbering is frequently left in. Figures 91 and 92 show the above case.

Brick Piers and Steel Girders.—Let a wall stressed with a load of 8 tons per lineal foot be carried by steel girders supported on brick piers in cement, the centre lines of which are 15 feet apart. Let the safe resistance of brickwork in cement be taken as 10 tons per super foot; cement concrete, 1 of Portland cement to 6 parts of ballast, 15 tons per super foot; and hard clay as 4 tons per super foot. The area of piers = total load on pier ÷ safe resistance of brickwork. Then

$$\text{Area of pier at top course} = \frac{15 \times 8}{10} = 12 \text{ super feet.}$$

Let weight of pier be taken as 20 tons.

$$\text{Area of pier at bottom course} = \frac{\text{total load on footings}}{\text{safe resistance of footings}} = \frac{120 + 20}{10} = 14 \text{ super feet.}$$

The resistance of this cement concrete being greater than the brickwork, it is unnecessary to calculate the footings.

Let the weight of the concrete be taken as 5 tons.

$$\text{Area of concrete} = \frac{\text{total load on earth}}{\text{safe resistance of earth}} = \frac{140 + 5}{4} = 36{\cdot}25 \text{ feet.}$$

Let the dimensions of the horizontal section of the concrete be taken as 6 ft. × 6 ft., and that of the brick pier as 3 ft. 9 ins. × 3 ft. 9 ins.

The clear span between piers will now equal 11 feet 3 inches, and the total distributed load will equal 90 tons;

Fig. 91.

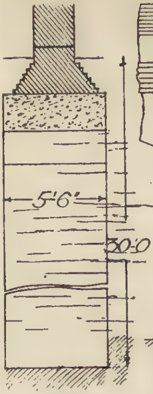


Fig. 92.

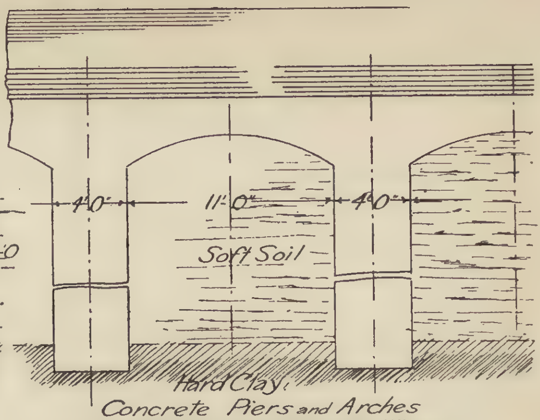
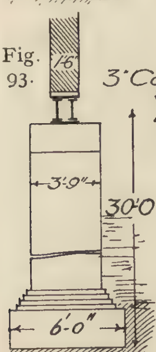


Fig. 93.



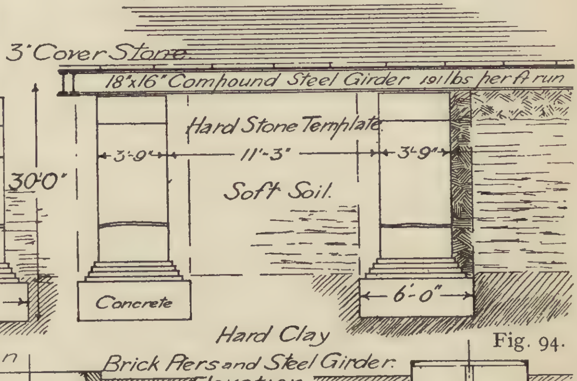


Fig. 94.

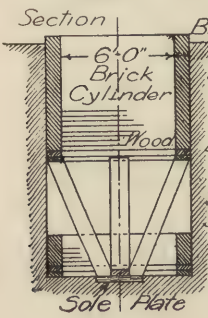


Fig. 95.

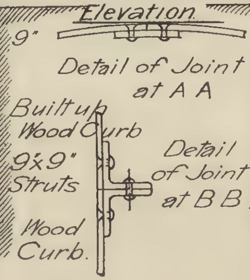


Fig. 97.

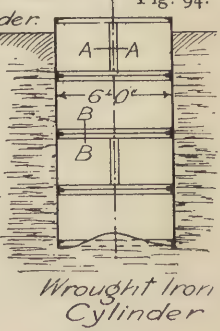


Fig. 96.

then from a manufacturer's list a 16 in. × 18 in. compound steel girder, 191 lbs. per foot run, will carry safely a distributed load of 96 tons over an 11 ft. 3 ins. span. Figures 93 and 94 illustrate this example.

Sinking Shafts.—Brick shafts are sunk in one of two ways. First, by the method known as underpinning. In this a circular hole is dug in the ground as deep as possible without causing the earth to fall, a circular built-up wood curb is then laid perfectly level at the bottom of the hole, on which the brickwork is raised to the top of the shaft, care being taken to pack the earth tightly behind the brickwork. When this part is completed, a hole is dug in the centre of the shaft as deep as possible, usually from 6 to 8 feet, a wood sole plate is bedded, inclined struts are then inserted, with one end resting on the plate, the other supporting the curb. At the completion of the fixing of these the earth is taken from beneath the curb at all parts to the level of the sole plate. A new curb is now inserted, and the brickwork built up to the underside of the old curb, and the struts removed. This process is repeated till the required depth is obtained, as shown in figure 95.

Second method: A wood curb similar to the one in the last method, or an iron curb with a sharp edge, is employed here. The curb is laid on the ground, and the brick or stonework raised upon it. The earth inside the curb is removed, and on being taken from beneath, the curb with the brickwork sinks, fresh courses of the latter being added as the sinking proceeds. It sometimes happens that the friction on the sides of the brick lining is so great as to prevent it from sinking; where this occurs, a second curb is placed inside the first, and a smaller shaft proceeded with in a manner similar to the first.

Iron Cylinder or Caissons.—This is sunk similarly to the brick shaft just described, fresh plates being added as the

earth is removed. These being in one mass, as shown in figure 96, there is less likelihood of their going out of the vertical; there is not so much friction on their sides, they therefore sink easier than the above, and are better where there is much water in the soil.

If the above-mentioned shafts have been sunk to the firm strata, they are usually filled with concrete, thus forming a number of solid pillars. These are connected by arches or girders, and upon these the superstructure is raised.

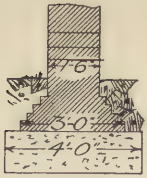
Where soft places such as underground brooks traverse the tracks of walls, it is usual to lay the concrete and bed the footings in the usual manner, and subsequently to build a rough relieving arch through the thickness of the wall over the soft parts, as shown in figures 98 and 99.

3. *Soils not having a Uniform Resistance.*—Soils of this description, where the ground consists of rock or firm ground in some parts, and in others of a soft soil, require careful treatment to prevent unequal settlement. The best method under these conditions is to cover the whole site with a bed of concrete, this being further strengthened by embedding steel rails into the concrete, spanning the soft parts; in this way a solid, hard platform is obtained over the whole site.

Slabs of concrete reinforced by steel rods of small section over the whole site forms an excellent foundation, distributing the weight by means of a slab thinner than would otherwise be needed, great tensile resistance being offered by the steel rods, thus preventing any fracture of the foundations due to movement in the substratum. Further and full description is given in the article on ferro-concrete.

Soft Soils Subjected to Unequal Pressures.—Where the pressures of a building are concentrated at piers placed at intervals in the length of the wall, there is a danger of unequal settlement and fractures in the unloaded portions of the walls; to counteract this tendency inverted arches,

Fig. 98.



Section.

Fig. 99.

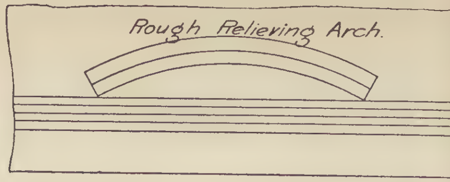
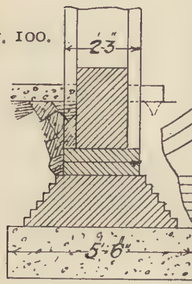


Fig. 100.



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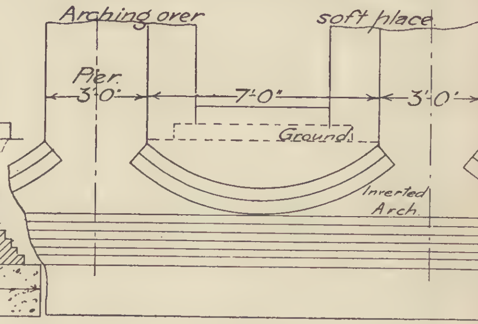
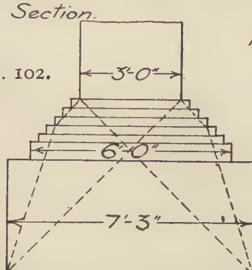


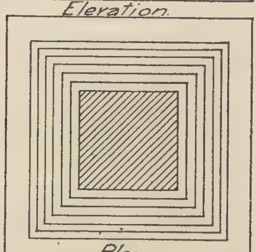
Inverted Arches.

Fig. 101.

Fig. 102.



Elevation.



Plan.

Empirical Rule for determining depth of Concrete.

Fig. 103.

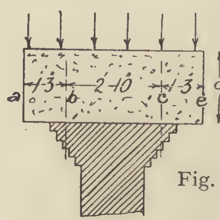
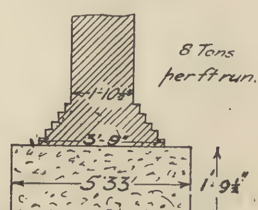


Fig. 104.

Pier Inverted.



Depth of Concrete determined by Calculation.

Fig. 105.

as shown in figures 100 and 101, are constructed between the piers, distributing the pressures uniformly over the whole length of the foundations.

Benching.—Where buildings are erected on the side of a hill, and it is not practicable nor economical to excavate the whole site of the building to one level, the ground should be benched—that is, cut into a number of horizontal steps; on these the foundations are laid and the walls raised. The wall, if of brick, should be carried up in cement to the highest level of the foundation, and in large blocks of stone if in masonry, in order to reduce the inequality of settlement due to the varying number of bed joints.

Subsoil Drainage.—In low-lying districts, and in damp soils generally, the site for any building should be drained thoroughly before the structure is commenced, especially if there is the remotest possibility of any future cuttings being made, such as would be required for sewers, railways, or excavations for buildings on a lower level, which, by acting as a drainage system, might cause the failure of the foundations and to prevent dampness rising up the walls and basement floors. Dampness in the soil that cannot drain away has a deleterious effect upon the health of the inmates, and also causes defects in the building: first, by the expansion and contraction of the earth, consequent upon the absorption and evaporation of moisture, which tends to rend the walls; secondly, the damp is drawn up the walls. This may be stopped by an efficient damp-proof course; but where a wood floor is built on the ground floor, the timbers will be liable to dry rot. This may to a certain extent be avoided by ventilating the timbers; but even under these conditions the timbers invariably rot by being subjected to alternations of dampness and dryness. To reduce the possibility of this defect, a layer of concrete at least 6 inches thick should be spread over the whole area covered by the building, and a damp-proof course over the whole site, as shown in figures 149 and 150 *Elementary Course.*

Where isolated buildings have to be erected, the method of draining the land would be as follows:—A trench or ditch is dug about the whole site to intercept any water that may flow over the land, and prevent it passing over the site. The site is divided into a number of parallel bays by narrower trenches than the above, all having a fall towards the lowest part of the site. Between these a number of still smaller trenches are cut, being arranged to a herring-bone pattern. These diverge from the centre line of the bay in the direction of the fall, and discharge into the above-mentioned trenches; the latter empty themselves into the enclosing ditch, from which the water is conveyed by

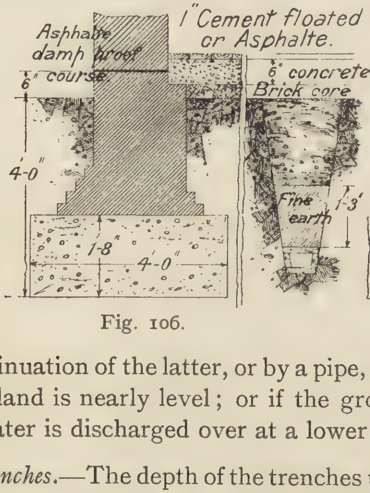


Fig. 106.

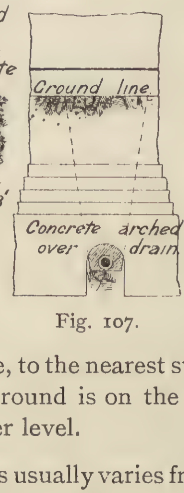


Fig. 107.

a continuation of the latter, or by a pipe, to the nearest stream, if the land is nearly level; or if the ground is on the slope, the water is discharged over at a lower level.

Trenches.—The depth of the trenches usually varies from $2\frac{1}{2}$ to 6 feet; they are cut as narrow as possible. The bottoms of the trenches are cut to regular falls of not less than 1 in 100. The distance between the smallest trenches varies with the soil, being about 20 feet in clay to 40 feet in lighter soils.

A duct is formed at the bottom of the trenches for the conveyance of water. This may be done in one of three ways, as follows:—(1) by placing a layer of large stones at the bottom of the trenches, through the interstices of

which the water can flow; (2) a channel is formed with tiles, either flat or curved, or of thin slabs of stone (as shown in figure 106)—where a thinly stratified stone is abundant, a space is left between the joints of the pieces to allow the water to drain into the channel; (3) agricultural drain pipes, as shown in figure 107, are used, being made of earthenware, usually about 15 inches in length and about 2 inches diameter in the smallest drains, and from 3 to 4 inches in the main drains. The pipes are laid dry, with a butt joint in the bottom of the trench; the ends are placed close together, the uneven surfaces leaving a sufficient space for the water to find its way through. Collars are sometimes placed over the joints to prevent dirt finding its way in, and to prevent the ends of the pipes getting removed from each other while the trench is being filled. The collars consist of a piece of pipe of a larger diameter than the drain, into which the ends of the latter fit loosely.

Filling In.—The space above the stones, tiles, or pipes should be filled in with a fine porous earth to a depth of at least 15 inches, and above this the ordinary earth may be placed, the latter being shot in lightly at first, but finally well rammed.

Failure and Prevention.—Such a drainage system is liable to failure from the following causes:—(1) by the accumulation of silt and vermin in the pipes; (2) roots of trees, which push the pipes out of their place and extend up the pipe, and finally stop them up; (3) where the pipes are under a building they are liable to fail by the settlement of the latter.

(1) The first danger may be avoided by building a catchpit at intervals, which consists of a brick chamber, into which the pipe discharges; all the matter in suspension falls to the bottom of the chamber, the fluid flows off through the continuation of the pipe on the opposite side of the catchpit. To prevent vermin, such as mice, etc., from getting up the pipes, all the outlets should be covered by a wire guard or broken glass.

(2) If laid near trees, collars should be employed, or socketed pipes set in cement.

(3) If occurring under the walls of a building, a space should be left and arched above them, in order that the pressure may not be brought to bear on the pipes on the settlement of the building and consequent compression of the earth.

In the model bye-laws issued by the Local Government Board, the following requirement is made :—" Every person who shall erect a new building shall cause the subsoil of the site of such building to be effectually drained by means ot suitable earthenware field-pipes properly laid to a suitable outfall whenever the dampness of the site renders such a precaution necessary. He shall not lay any such pipe in such a-manner, or in such a position, as to communicate directly with any sewer or cesspool, or with any drain constructed or adapted to be used for conveying sewage, but shall provide a suitable trap with a ventilating opening at a point in the line of the subsoil drain as near as may be practicable to such trap."

Width and Depth of Concrete Foundations.—For heavy buildings the width of the concrete in the foundation should be determined by the bearing strength of the ground on which it rests. The following table is useful in calculating the width :—

Table of Safe Loads in Tons, per super foot.	Tons.
Brickwork in mortar (sound stocks), grey chalk lime and sand, 1 to 2, six months old	$2\frac{1}{2}$
Lias lime and sand, 1 to 2, six months old	5
Brickwork in cement (hard stocks), Portland cement and sand, 1 to 1, three months old	10
(Ordinary well-burnt stocks) Portland cement and sand, 1 to 1, three months old	8
Concrete—Portland cement and river ballast, 1 to 6, 12 months old	15 to 20
Lias lime and river ballast, 1 to 6, 12 months old	$2\frac{1}{2}$ to $4\frac{1}{2}$
Rubble masonry in lias lime	4

The following table of safe resistances of earth is given by Newman :—

Description of Earth.	Approximate safe Maximum load in tons per square foot.
Bog, morass, quicksand, peat moss, marsh land, silt	0 to 0·20
Slake and mud, hard peat turf	0 to 0·25
Soft wet pasty or muddy clay, and marsh clay ...	0·25 to 0·33
Alluvial deposits of moderate depths in river beds, etc.	0·20 to 0·35
Note.—When the river bed is rocky and the deposit firm, they may safely support 0·75 tons, but not more.	
Diluvial clay beds of rivers	0·35 to 1·00
Alluvial earth, loams and loamy soil (clay and 40 to 70 per cent. of sand), and clay loams (clay and about 30 per cent. of sand), damp clay	0·75 to 1·5
Loose sand in shifting river bed, the safe load increasing with depth	2·50 to 3·00
Upheaved and intermixed beds of different sound clays	3·00
Silty sand of uniform and firm character in a river bed secure from scour, and at depths below 25 feet	3·5 to 4·00
Solid clay mixed with very fine sand	4·00
Note.—Equal drainage and conditions is especially necessary in the case of clays, as moisture may reduce them from their greatest to their least bearing capacity. When found equally and thoroughly mixed with sand and gravel, their supporting power is usually increased.	
Sound yellow clay containing only the normal quantity of water	4·00 to 6·00
Solid blue clay, marl and indurated marl, and firm boulder gravel and sand	5·00 to 8·00
Soft chalk, impure and argillaceous	1·00 to 1·50
Hard white chalk	2·50 to 4·00
Ordinary superficial sand beds	2·50 to 4·00
Firm sand in estuaries, bays, etc.	4·50 to 5·00
Note.—The Dutch engineers consider the safe load upon firm clean sand as 5½ tons per square foot.	

Description of Earth.	Approximate safe Maximum load in tons per square foot.
Very firm compact sand foundations at a considerable depth not less than 20 feet, and compact sandy gravel	6·00 to 7·00
Note.—The sustaining power of sand increases as it approaches a homogeneous gravelly state.	
Firm shale, protected from the weather in clean gravel	6·00 to 8·00
Compact gravel	7·00 to 9·00
Note.—The relative bearing powers of gravel may be thus described:—	
1. Compact gravel; 2. Clean gravel; 3. Sandy gravel; 4. Clayey or loamy gravel.	
Sound, clean, homogeneous Thames gravel has been weighted with 14 tons per square foot at a depth of only 5 feet below the surface, and presented no indication of failure. This gravel was similar to that of a clean pebbly beach.	
Rocks for foundations and general work	8·00 to 18·00
Rocks, sandstones that may be crumbled in the hand	1·50 to 1·75

There are two methods of approximately determining the bearing resistance of the soil: 1st, by taking a square piece of wood of a given area, say 1 foot, and loading same until the ground is impressed; 2ndly, by taking a bar of iron, of given sectional area, and dropping the same from a given height and noting the depth to which the bar sinks into the ground before it comes to rest, and then deducing from the laws of falling bodies the resistance that has been offered.

EXAMPLE: An iron bar 6 in. × 6 in. in section, weighing 30 lbs., falls freely through a height of 10 feet, and is found

to sink into the ground $\frac{1}{2}$ in. Then, by Major Saunders' formula,

$$R = \frac{W \times h}{d}$$
$$= \frac{30 \times 120}{\frac{1}{2}}$$
$$= 7{,}200 \text{ lbs. per 36 square inches.}$$

$\therefore$ for 1 square foot R = 28,800 lbs., and for safety let $\frac{28800}{8} = 3{,}600$ lbs. per square foot.

At a depth of 3 feet the maximum load in London is usually taken as $1\frac{1}{2}$ to 2 tons per super foot. Thus, if a brick wall built in lias lime mortar will safely carry 5 tons per superficial foot of section, and assuming the earth to be capable of supporting safely a uniform load of $1\frac{1}{2}$ tons per super foot, then the width of concrete should be $5 \div 1\frac{1}{2}$, or nearly 3·33 times the thickness of the wall. The depth or thickness of the concrete is usually determined by experience, but as the most dangerous fracture that is likely to occur in concrete foundations is at the angle of about 45° to the base, causing the foundations to rupture in a number of triangular prisms or pyramids shearing or sliding upon each other, it would be better determined by drawing lines as in figure 102, inclined 45° to the plane of the bottom of the wall above the footings from the thickness of the wall, and the depth required is shown by the intersection of these lines with the vertical lines, indicating the width of the concrete, supposing that the base of the foundations is on ground that is not likely to escape laterally under pressure.

The following illustrates the application of this theory to piers:—

EXAMPLE: Calculate the necessary dimensions of brick footings, and the width and depth of concrete for a square brick pier of 3 feet side, stressed to 5 tons per square foot of section, the safe loads of lias lime concrete and earth being taken as 3 and 1 tons per super foot respectively.

The area of the base of the footings in feet will be the

total load divided by the safe load per super foot of concrete. Let the weight of the brick footings be taken as approximately 1 ton, then—

$$\frac{\text{Total load}}{\text{Safe load upon concrete}} = \frac{45 + 1}{3} = 15\tfrac{1}{3} \text{ feet super.}$$

The side of base footings will therefore equal in nearest brick dimensions 4 ft. $1\frac{1}{2}$ in.; but it is usual to make the side of lowest course of footings twice the width of the pier, that is in this case 6 ft.

The area of the base of the concrete in feet will be the total load divided by the safe load sustained per super foot by the earth. Let the weight of the concrete be taken as approximately 5 tons, then—

$$\frac{\text{Total load}}{\text{Safe load upon earth}} = \frac{45 + 1 + 5}{1} = 51 \text{ feet super,}$$

and the side of base of concrete will therefore equal 7·14 ft., say 7 ft. 3 in., as shown in figures 102 and 103.

Figure 102 shows, in dotted lines, the calculated footings and concrete to satisfy the preceding calculations and the bye-laws, the brick footings being splayed at the usual angle, and the depth of concrete being determined by drawing lines at 45° from base of wall and the point of intersection with the calculated width of concrete, will give the depth, as previously explained. Figure 102 shows how the brick footings are usually arranged in practice, which, in this case, may be supposed to be substituted for the equivalent depth of concrete.

Depth of Concrete by Calculation.—The depth of concrete may be obtained by calculating as for a cantilever under a distributed load, therefore the formula, as given in the chapter on girders, is—

$$\text{M L} = \text{M R}$$

$$\frac{w l^2}{2} = \frac{fo \times b \times d^2}{6}$$

$$\therefore \quad d^2 = \frac{6 \, w \, l^2}{2 \, fo \, b}$$

EXAMPLE: In a wall of 1 foot $10\frac{1}{2}$ inches thick, there is a load of 8 tons upon every lineal foot. Determine the depth of cement concrete required. The value of C or *fo* is given as 2·5 cwts., and the factor of safety is to be $\frac{1}{8}$ of the ultimate resistance.

Let the safe resistance of the earth be taken as $1\frac{1}{2}$ tons per superficial foot, then the

$$\text{Width of concrete} = \frac{\text{total load}}{\text{safe resistance of earth}}$$

$$\text{,, \quad ,, \quad ,,} \quad = \frac{8}{1\frac{1}{2}} = 5\cdot33 \text{ feet.}$$

The figure 104 shows the wall inverted to realize more clearly the pressure. The part between *b* and *c* may be considered as under compressional stress only, whilst the distances *a b*, *c e*, represent the lengths of the cantilevers

$$\frac{w\,l^2}{2} = \frac{fo \times b \times d^2}{6}$$

but for safety let a factor of $\frac{1}{8}$th be taken,

$$\text{then } \frac{w\,l^2}{2} = \frac{fo \times b \times d^2}{6 \times 8}$$

$$\therefore \quad d^2 = \frac{6 \times 8 \times w\,l^2}{2 \times fo \times b}$$

but distributed load in cwts. per inch of length of cantilever $= \frac{160}{64}$

$$\therefore \quad d = \sqrt{\frac{6 \times 8 \times 160 \times 15 \times 15}{2 \times 2\frac{1}{2} \times 12 \times 64}}$$

$$d = 21\cdot21 \text{ inches.}$$

Steel and Concrete Foundations.—A common method of constructing foundations of walls and piers of buildings where the structure rests upon a yielding stratum, is to embed steel joists in concrete in order to extend the bearing surface. The methods of employing timber in foundations is defective unless it is known that the same can be kept permanently wet or dry, or they quickly rot. Iron or steel

rails embedded in concrete are not open to this objection, but where great weights are concentrated on points or lines, as under piers or walls, the rails are subject to deflection unless the concrete bed is very thick. I beams as now used are in every way superior to the above, as by employing a depth enough to reduce the deflection to a minimum, a comparatively thin bed of concrete only need be used, and a sufficient saving be effected in excavation and concrete to compensate for the employment of the steel beams.

This method of constructing foundations is especially suitable where the structure is erected upon a comparatively thin hard stratum overlying a soft and yielding stratum, and where consequently it would be unwise to damage the upper crust.

To prepare foundations in this manner it is usual to lay a bed of concrete of from 4 to 12 inches in thickness, and on this to place the beams at right angles to the wall at centres varying from 9 inches to 24 inches, as shown in figures 108 and 109.

EXAMPLE: A wall 1 foot $10\frac{1}{2}$ inches in thickness supports a load of 15 tons per lineal foot. The width of footings at base to comply with bye-laws is 3 feet 9 inches. The safe bearing strength of earth is $1\frac{1}{2}$ tons per superficial foot; therefore—

$$\text{the width of foundation} = \frac{\text{total load}}{\text{safe resistance of earth}}$$

$$= \frac{15}{1\frac{1}{2}} = 10 \text{ feet.}$$

Taking the distance of centre of projection of footings to edge of foundations on either side to equal 3 feet $7\frac{1}{8}$ inches, say 3 feet 7 inches, and the rolled steel joists to be placed at 2 feet centres, and from a manufacturer's list that a 5 in. × 12 in. joist with flanges ·56 inch thick and web .35 inch, determine the stress per square inch in section.

From the formula for cantilevers under distributed loads (see chapter on Girders)—

$$\frac{wl^2}{2} = \frac{fo\ \mathrm{I}}{\delta}$$

$$\text{but } \mathrm{W} = wl$$

$$\therefore \frac{\mathrm{W}l}{2} = \frac{fo\ \mathrm{I}}{\delta}$$

$$\therefore fo = \frac{\delta\ \mathrm{W}l}{2\ \mathrm{I}}$$

$$\text{but } \mathrm{I} = \frac{bd^3 - b'\,d'^3}{12}$$

$$\mathrm{I} = \frac{(5 \times 12^3) - (4{\cdot}65 \times 10{\cdot}88^3)}{12}$$

$$\mathrm{I} = 220{\cdot}95$$

$$\text{and } \delta = 6 \text{ and } \mathrm{W} = \frac{43}{12} \times 2 \times 1\tfrac{1}{2} = 10{\cdot}75 \text{ tons}$$

$$\text{and } l = 43 \text{ inches}$$

$$\therefore fo = \frac{6 \times 10{\cdot}75 \times 43}{2 \times 220{\cdot}95} = 6{\cdot}27 \text{ tons.}$$

that is, the maximum stress on each square inch in section is 6·27 tons. This section may therefore be safely used, as it gives a factor of safety of nearly $\frac{1}{5}$th, and an amount of stiffness is undoubtedly acquired by being embedded in concrete, as shown in figures 108 and 109.

Grillage Foundations.—In the case of piers, steel joists are placed in two systems crossing each other. This arrangement is termed a grilled foundation. The space between the joists is then filled in with concrete, care being taken to work the same well in between the flanges.

Figures 110 to 112 show the method of constructing a grilled foundation, the weight of the building being supposed to be transmitted to the ground through piers.

EXAMPLE: Let a wall be supported on pillars 12 feet centres, the distributed load per lineal foot being 15 tons; therefore, the weight upon each pillar will be 180 tons—that is, there will be the same total stress upon the lower system of joists as in the 5 in. × 12 in. joists of the preceding

Fig. 108.

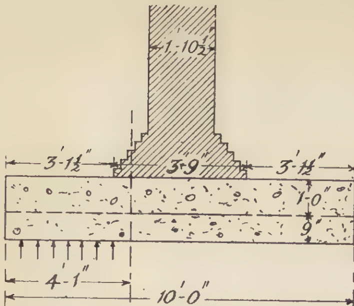
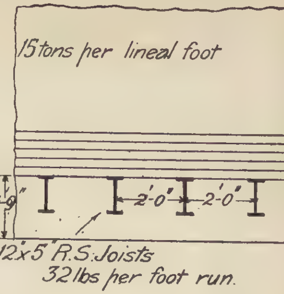


Fig. 109.



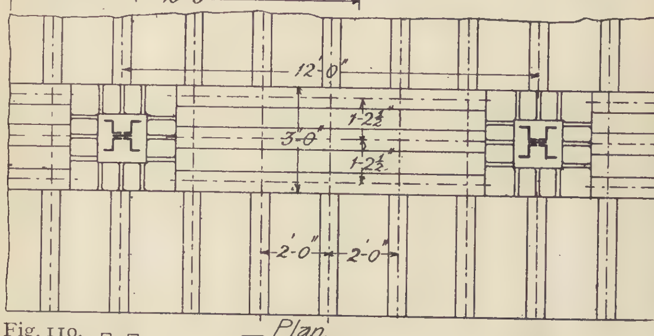


Fig. 110.

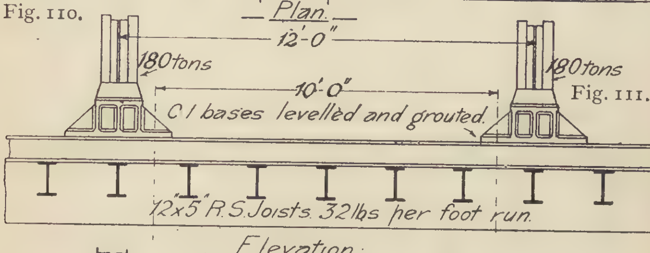


Fig. 111.

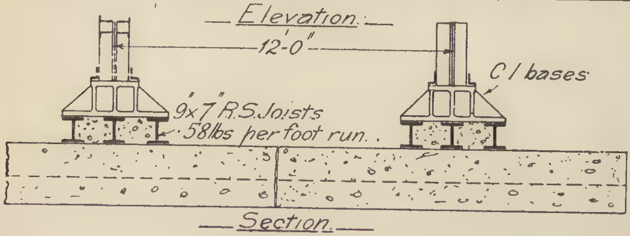


Fig. 112.

example, if arrangements are made to distribute the stresses. Determine, therefore, the section required for the upper system, the factor of safety to be not less than $\frac{1}{3}$, the ultimate resistance of the steel joists being 32 tons. The lower system may be arranged as in the last example.

This is practically a case of a beam fixed at both ends under a distributed load with spans of 10 feet, as shown in figure 111.

From the manufacturer's list is taken a steel joist 7 in. × 9 in., flanges ·81 thick, web ·77 thick, and I = 216·81.

The length of the beam, as shown in figure 111, may be taken as 10 feet, and the distributed load as 15 tons per lineal foot, the 2 feet under the pillar being considered as under direct compression.

$$\therefore \text{total distributed load on each of the three girders} = \frac{10 \times 15}{3} = 50 \text{ tons.}$$

Therefore, by the formula—

$$\therefore \frac{wl^2}{12} = \frac{fo\,\mathrm{I}}{\delta}$$

$$\therefore \frac{\mathrm{W}l}{12} = \frac{fo\,\mathrm{I}}{\delta}$$

$$\therefore fo = \frac{\delta \mathrm{W}l}{12\,\mathrm{I}}$$

$$fo = \frac{4{\cdot}5 \times 50 \times 120}{12 \times 216{\cdot}81}$$

$$= 10{\cdot}3 \text{ tons per square inch.}$$

Figures 110 to 112 illustrate this example, and give all the necessary details.

The bye-laws of the London County Council include the following provision as to the least dimensions of the concrete foundation :—

The foundations of the walls of every house or building shall be formed of a bed of good concrete not less than 9 *inches thick*, and projecting at least 4 inches on each side of the lowest course of footing of such walls. If the site be upon a natural bed of gravel, concrete will not be required.

Footings.—Footings are the extended portion at the base of a brick or stone wall; the construction of the footings will be found treated in the *Elementary Course.*

The following weights of different earths are given by Newman:—

Name of Earth.	Weight.	
	Decimals of a ton. Cubic foot.	Tons. Cubic yard.
Basalt, solid	0·083	2·25
Bath Stone, solid	0·052	1·40
Chalk, damp to wet, loose to close ...	0·056 to 0·074	1·50 to 2·00
Clay	0·054 to 0·059	1·45 to 1·60
Flint, solid	0·074	2·00
Granite	0·078	2·10
Gravel and Shingle	0·046 to 0·055	1·25 to 1·50
Limestone Lias to Compact Mountain	0·067 to 0·078	1·81 to 2·10
Marl	0·044 to 0·052	1·20 to 1·40
Mud at surface...	0·044	1·20
Mud at about 15 ft. in depth ...	0·048	1·30
Peat, hard and top mould	0·036	0·98
Portland Stone, solid	0·065	1·75
Quartz, solid	0·076	2·05
Sand, dry river	0·041	1·10
Sand, damp and shaken	0·055	1·50
Sandstone, solid	0·063 to 0·072	1·70 to 1·95
Shale	0·074	2·00
Slate, solid	0·08	2·15
Trap, solid	0·078	2·10

CHAPTER III.

BRICKWORK.

CONTINUED FROM THE AUTHOR'S ELEMENTARY COURSE.

STABILITY OF WALLS.

WALLS made of such materials as brick or stone may be supposed, for the purposes of calculation, to be composed of (*a*) uncemented blocks, or (*b*) cemented blocks. Walls may be satisfactorily considered as built of uncemented blocks, when the force disturbing its equilibrium acts before the bedding or joining substance has had time to set, that is, obtains an adhesion and tenacity equal in strength to the materials which are held together, or possesses sufficient of those two resisting powers to withstand the disturbing force. Hence it follows that walls, such as chimney stacks, chimney shafts, buttresses, etc., work where the failure of one joint would be disastrous, work that cannot be or is not strutted, nor otherwise supported, and will probably have to resist a disturbing element such as wind force before the bedding material has had time to set; such walls should be calculated as if made of uncemented blocks.

Minimum Thickness.—The thickness of walls of dwelling-houses and warehouses has been determined by vast expe-

rience, and the minimum thickness is given on page 235, and no advantage would therefore be derived from calculating the same, although it would be more satisfactory if a dangerous wall were more sharply defined; as the practice given by an eminent authority in these matters, that he should consider a wall overhanging one in twenty-four not unsafe, and dangerous when it over-hangs one in twelve; although useful as a guide, for which purpose it was given, can scarcely be considered a final and satisfactory conclusion.

Fence or boundary walls are usually calculated as built up with a number of cemented blocks—that is, the strength of the mortar is considered, for it may be easily shown that the thickness of the majority of fence walls would be insufficient, were it otherwise, to resist the wind pressures frequently obtained.

Classification of Failures.—A wall consisting of uncemented blocks (that is, supposing lime mortar to be used, its tenacity and adhesion being neglected) may fail from the following causes:—(*a*) By the overturning of some one or more blocks on their edges; (*b*) by crushing if the pressure be great enough and distributed over too small a surface; (*c*) by the sliding of some one or more of the blocks on their bed joints.

Overturning.—Consider proposition (*a*). If the wind pressure is to be considered as the external disturbing force, multiply the superficial area of wall face by the wind pressure (P), and by its leverage, which is equal to one-half of the height of the wall, the product will be the value of the moment of the disturbing element. Therefore, the moment of the wind pressure or its power to overturn the wall may be represented by the formula, exposed surface × P × leverage, which in an ordinary wall with rectangular faces

would give $(h \times l) \times (\mathrm{P}) \times (h \div 2)$, when P = pressure of wind in lbs. per square foot, l = length of wall usually in feet, h = height of wall usually in feet against a surface perpendicular to its direction.

Assuming that the strength of the materials and the accuracy of the bonding is uniform throughout a wall, its power to resist external forces, neglecting strength of mortar, will depend upon the leverage of external forces as compared with the leverage of the mass or weight of the wall acting at its centre of gravity. One edge of the wall at its base may be considered as a fulcrum; the weight of the wall acts with a leverage equal to one-half the thickness of the wall. Therefore, the moment of the mass of the wall, or its power to resist external forces, may be represented by the formula, cubic content $\times$ W $\times$ leverage, which in an ordinary wall of the rectangular prismatic type might be stated as $(l \times t \times h) \times (\mathrm{W}) \times (t \div 2)$, when t = thickness of wall (usually in feet), W = weight (usually in lbs.) per foot cube of wall material, other symbols as stated previously. When the moment of the wind pressure equals the moment of the mass of the wall, the structure is on the brink of overturning, the pathway of the centre of pressure passing through the centre of gravity of the wall, and that edge of the wall which is acting as the fulcrum. Under these conditions walls may be described as in unstable equilibrium. The equation for walls in unstable equilibrium of the usual form may be stated thus:—

Moment of wind pressure = Moment of mass of wall.

$$(l \times h) \times (\mathrm{P}) \times (h \div 2) = (l \times t \times h) \times (\mathrm{W}) \times (t \div 2)$$

It is sufficient for the purposes of calculation to consider a portion of the wall 1 foot in length, as that factor appears on both sides of the equation.

The following is a table giving the velocity and pressure of winds, or the value of P.

TABLE SHOWING THE VELOCITY AND PRESSURE OF WINDS.

Designation.	V = Velocity in miles per hour.	P = Pressure in lbs. per square ft.
Scarcely perceptible	1	·005
Perceptible	2	·020
Slight breeze	4	·080
Moderate ,, ...	8	·320
Fresh ,, ...	15	1·125
Brisk wind	25	3·125
Strong ,, ...	30	4·50
High ,, ...	40	8·00
Storm	50	12·50
Violent storm...	60	18·00
Hurricane	80	32·00
Violent hurricane	100	50·00
Gust observed in England in 1866...	126	80·00

Let P = pressure of wind in lbs. per square foot against a surface perpendicular to its direction.

If the velocity in miles per hour is known, the value of P may be deduced from the empirical formula $P = V^2 \div 200$, or if P is given, $V = \sqrt{200\ P}$.

Crushing.—Consider the walls for safety from crushing, as the equation already stated only satisfies proposition (*a*), and represents unstable equilibrium or the brink of overturning. This condition of safety is usually fulfilled by making the wall of sufficient thickness to meet the requirements of proposition (*b*), which is complied with when the centre of pressure falls sufficiently within the walls for the section of the wall to resist crushing where the stress is at its maximum, which in a wall of ordinary section is at the ground line and on its outer edge.

Where the resultant of wall and overturning pressures intersect a base or bed joint of a wall, at a distance of one-third or less of the thickness of the wall from the outer edge, the section under compression will be three times that distance.

Taking for example a wall the centre of pressure of which

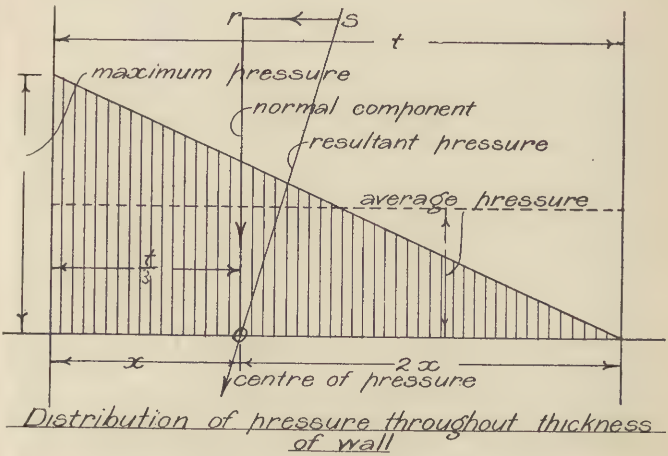


Fig. 113.

is one-third of its thickness from its outer edge, the pressures are found to vary as the ordinates of a triangle, the maximum pressure being on the overturning edge to zero on the inner edge of wall. The value of the pressure on the overturning edge will be twice the average pressure on the compressed section of the base, as shown in figure 113.

The section under compression will be stressed to the value of the component normal to the bed joint of the resultant pressure. Therefore for calculations, taking a unit length of wall, determine—

(1) The distance of the centre of pressure from outer edge.

(2) Multiply by three this distance; if the latter is a third or less of the thickness of the bed joint, this product into a unit length will be the compressed area.

(3) The value of the normal component divided by this area will equal the average pressure per unit area.

(4) Twice the average pressure will be the maximum pressure on the outer edge, which should not exceed the safe resistance of the material. The units usually taken are inches and lbs.

It is useful to know the limiting position of the centre of pressure often adopted which for ordinary building materials satisfies proposition (*b*); this is given in the following table.

Limiting Position of the Centre of Pressure.

(*Rankine.*)

If a line in the direction of the force be drawn through the centre of gravity of base, then let

A = the point where line intersects side not exposed to the force.

B = the point where line intersects side which is exposed to the force.

C = the extreme position of the centre of pressure.

Figure of base, or bed joint under consideration.	Distance from outside edge.
Rectangle solid	A C = $\frac{1}{3}$ A B
Square solid	A C = $\frac{1}{3}$ A B
Ellipse solid	A C = $\frac{3}{8}$ A B
Circle solid	A C = $\frac{3}{8}$ A B
Hollow square (factory chimneys) ...	A C = $\frac{1}{6}$ A B
Circular ring (factory chimneys) ...	A C = $\frac{1}{4}$ A B

Example:—A chimney stalk rises 20 feet clear of roof; find thickness required to resist wind pressure of 56 lbs. per square foot, neglecting the resistance of the mortar. Assume

the chimney stalk to weigh 60 lbs. per foot cube on an average.

For calculation, take a length of one foot of wind pressure and chimney.

The equation for equilibrium or on the brink of overturning is, as already stated, as follows:—

$$\text{Moment of wind pressure} = \text{Moment of weight of chimney.}$$
$$P \times h \times l \times \tfrac{h}{2} = w \times h \times l \times t \times \tfrac{t}{2}$$

The limiting position of the centre of pressure, as may be seen from number five line of the given table, is one-sixth of the required thickness from the lee side, therefore the perpendicular distance from the centre of gravity of the wall to the limiting position of the centre of pressure will be the thickness over three. This will satisfy (*a*) and (*b*) conditions for safety, whilst (*c*) proposition may easily be tested for safety by drawing the diagram of resultant pressure and bed joints, and noting whether it satisfies the rules given in the following paragraph on Sliding. Therefore the equation for safety becomes—

$$\text{Moment of wind pressure} = \text{Moment of weight of chimney.}$$
$$P \times h \times l \times \tfrac{h}{2} = w \times (h \times l \times t) \times \tfrac{t}{3}$$
$$56 \times 20 \times 1 \times 10 = 60\,(20 \times 1 \times t) \times \tfrac{t}{3}$$
$$11200 = 400\,t^2$$
$$t^2 = 11200 \div 400$$
$$t^2 = 28$$
$$t = \sqrt{28} \text{ or } 5{\cdot}3 \text{ ft. nearly.}$$

Example:—What wind force per foot super would overturn a 14-inch brick wall 10 feet high and weighing 108 lbs. per foot cube, neglecting the strength of the mortar ?—(*Science Exam. Honours.*)

$$\text{Moment of wind pressure} = \text{Moment of mass of wall.}$$
$$P \times h \times \tfrac{h}{2} = w \times h \times t \times \tfrac{t}{2}$$
$$P \times 10 \times 5 = 108 \times 10 \times 1{\cdot}16 \times {\cdot}58$$
$$50\,P = 726{\cdot}624$$
$$P = 14{\cdot}532 \text{ lbs.}$$

Sliding.—The stability of walls with respect to proposition (*c*) or sliding will now be considered. If a rough plane with a body upon it be gradually tilted, there is a certain angle to the horizontal when sliding is about to take place. This angle is known as the "angle of repose," and the ratio of the height of such a plane to its base is known as the co-efficient of friction. The angle of repose has been determined experimentally for a number of materials. It is not difficult to draw the resultant pressure and note the angle which it makes with the normal to the bed joints. The direction of the resultant pressure must not make a greater angle with the normal to bed joint than the angle of repose. For safety it is usual not to let the angle which the direction of the resultant pressure makes with the normal to the bed joint exceed the angle of which 0·8 of the co-efficient of friction of the material is the tangent.

GENERAL MORIN'S TABLES.

Surfaces.	Angle of Repose.	Co-efficient of Friction.
Dry masonry and brickwork	31° to 35°	0·6 to 0·7
Masonry and brickwork with wet mortar ...	25½°	0·47
Masonry and brickwork with slightly damp mortar...	36½°	0·74
Wood on stone	22°	0·4
Iron on stone	16⅔° to 35°	0·3 to 0·7
Masonry on dry clay	27°	0·51
Masonry on moist clay	18¼°	0·33
Earth on earth	14° to 45°	0·25 to 1·0
Earth on dry sand, clay, and mixed earth ...	21° to 37°	0·38 to 0·75
Earth on damp clay	45°	1·0
Earth on wet clay	17°	0·31
Earth on shingle and gravel	35° to 48°	0·7 to 1·11

Side Thrusts.—The overturning pressures from rafters, vaults or similar forces upon walls may be calculated as follows :—

Example :—A rectangular wall, 10 feet high, has to resist

a thrust of 500 lbs. per foot run applied at an angle of 60° to the horizon at a height of 8 feet above the ground level.

Taking the weight of the wall at 100 lbs. per foot cube, what must be its thickness, supposing it to be unstable without taking into consideration the strength of the mortar ?

Let a length of 1 foot be taken.

500 lbs. at 60° to the horizon will give a horizontal component of 250 lbs. and a vertical component of 433 lbs. The point of application is 8 feet high on the thrust side. Let the force be here resolved into its horizontal and vertical components, then for unstable equilibrium—

$$\left.\begin{array}{l}\text{Moment of horizontal com-}\\ \text{ponent of pressure}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of vertical compo-}\\ \text{nent of pressure + moment}\\ \text{of mass of wall}\end{array}\right.$$

$$250 \times 8 \times l = (433 \times t) + (h \times t \times l \times w)\frac{t}{2}$$

Let a length of 1 foot be taken, then—

$$2000 = (433\,t) + (10 \times t \times 1 \times 100)\frac{t}{2}$$

$$2000 = 433\,t + 1000\frac{t^2}{2}$$

$$500\,t^2 + 433\,t = 2000$$

$$t^2 + \frac{433}{500}t = 4$$

$$t^2 + \frac{433}{500}t + \left(\frac{433}{1000}\right)^2 = 4 + \left(\frac{433}{1000}\right)^2$$

$$t + \frac{433}{1000} = \pm\ 2{\cdot}046$$

$$t = 2{\cdot}046 - {\cdot}433$$

$$t = 1{\cdot}613 \text{ ft.}$$

This problem could be worked with the same result by imagining the force continued till it intersected the vertical

passing through the centre of gravity of the wall. The statement would then be—

$$\left.\begin{array}{l}\text{Moment of horizontal com-}\\ \text{ponent of pressure}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of vertical compo-}\\ \text{nent of pressure + moment}\\ \text{of mass of wall}\end{array}\right.$$

$$250\left(8 - \frac{\sqrt{3}}{2}t\right) = \left(433\frac{t}{2}\right) + \left(h \times t \times l \times w\right)\frac{t}{2}$$

The following table, compiled from Wray and Rankine, will be found useful :—

STRENGTH OF MORTAR.

	Tension. lbs. per sq. in.	Adhesion. lbs. per sq. in.
Mortar composed of one part of Portland cement to two of sand (after a very short time)	280	280
Do., one part blue lias lime to two of sand with hard grey stocks	140*	36†
Do., do., with place bricks	—	18†

Mortar made with weak hydraulic lime, or pure lime and sand, possesses such a small amount of strength that practically it may be neglected.

In ascertaining the strength of walls on this principle, only the lowest value of the mortar (whether tension or adhesion to brickwork) should be taken.

For practical purposes it may be considered that after allowing time for setting, say from three to six months, according to the value of the mortar, good stock brickwork will begin to fail by cracking at a pressure of 200, 400, or 700 lbs. per square inch according as it is laid in grey chalk lime, lias lime, or Portland cement mortar. For ultimate crushing from one and a half to twice these pressures would be required.

Structures with Cemented Blocks.

The following method of calculation is used in the case of chimneys and shafts built in Portland cement mortar;

* After 7 days. † After 6 months.

it is also used for enclosure walls, short projections, and works of minor importance.

Wind pressure is the principal disturbing force acting on walls, and those joints which have to withstand the greatest stress are at the lowest position, where the wind exerts the greatest turning moment.

If the wall be of uniform section throughout, it is quite sufficient if the strength of the lowest joint be calculated; but if the thickness be variable, the lowest joint at each change of section must be taken.

It follows from the above, that since there is less stress on the joints in the upper portion, in many cases a wall might very well be built in lime mortar with only the joints in the lowest portion made with cement mortar.

In addition to external forces there is an internal compressive force due to the weight of the mass of the wall itself. Under certain conditions, however, as in some retaining walls where the joints are not horizontal, this force may cause a portion of the joint to be subjected to a shearing stress, though the strength of mortar and the resistance due to friction are always more than sufficient to withstand that force.

To ascertain the pressure of the wall on the joints, divide the weight of the wall in pounds by the horizontal sectional area in inches, and the result will be the pressure in pounds per square inch—

Let A be the windward side of the wall.
,, B ,, leeward ,, ,,
,, M ,, pressure of the wall at A.
,, N ,, ,, ,, ,, B.

In ordinary cases M and N are equal. The moment of resistance would equal the strength in tension or compression, and be symbolised by (fo).

Hence the pressure at $A = M + ft$. (The algebraical sum.)

Hence the pressure at $B = N + fc$.

From the foregoing, it will be seen that the strength of the wall may be represented by the following equation :—

$$\left.\begin{array}{c}\text{Moment of wind pressure} + \\ \text{pressure on joint}\end{array}\right\} = \left\{\begin{array}{l}\text{Moment of resistance of the} \\ \text{joint.}\end{array}\right.$$

The "moment of wind pressure" is the pressure (P) multiplied by the area on which it acts ($h \times l$) multiplied by the leverage $\left(\frac{h}{2}\right)$; and the "moment of resistance" of the joint is the strength in tension or compression multiplied by the moment of inertia (I) divided by the tendency to break (δ). The moment of inertia has been shown to be in rectangular bodies the breadth multiplied by the cube of the depth divided by 12, and the tendency to break is the mean distance of the particles from the neutral axis, or half the depth. For present purposes let us consider the wall as a vertical cantilever, and in this case the thickness of the wall would be the depth (D).

The formula may be expressed symbolically thus :—

$$\mathrm{P} \times (h \times l) \times \left(\frac{h}{2}\right) = \frac{fo \times \mathrm{I}}{\delta}$$

The method of applying this will be shown by the working of the following example :—

Example :—A long enclosure wall 12 feet high, 2 bricks thick, set in hydraulic mortar and weighing 100 lbs. per cubic foot, built in an exposed position in a country where the wind has registered a pressure of 55 lbs. per square foot. Determine the compression on the lee side and the tension on the wind side.

$$\mathrm{P} \times (h \times l) \times \frac{h}{2} = \frac{fo\ \mathrm{I}}{\delta}$$

$$\frac{55}{144} \times 144 \times 12 \times \frac{144}{2} = \frac{fo \times \frac{bd^3}{12}}{\frac{d}{2}}$$

$$\frac{55 \times 144 \times 12 \times 144}{144 \times 2} = \frac{fo \times 12 \times 18^3 \times 2}{18 \times 12}$$

$$47520 = 648\,fo$$

$$fo = \frac{47520}{648}$$

$$fo = 73\dot{3}$$

The above being a wall rectangular in section, there would be an equal pressure from the wind on both sides with this difference, that on the windward side is a tensional, and that on the leeward a compressional stress.

The pressure of the mass of the wall may be found thus:

$$W \times h \times t \times l = P.$$
$$100 \times 12 \times 1\tfrac{1}{2} \times 1 = 1{,}800 \text{ lbs.}$$
$$\text{Area} = 18 \times 12 = 216 \text{ sq. ins.}$$
$$\therefore \frac{1800}{216} = 8\cdot\dot{3} \text{ lbs. per sq. in.}$$

Then pressure on windward side $= 73\cdot\dot{3} - 8\cdot\dot{3} = 65$ lbs. per square inch under tension.

Then pressure on leeward side $= 73\cdot 3 + 8\cdot\dot{3} = 81\cdot\dot{6}$ lbs. per square inch under compression.

Under such circumstances a wall set in hydraulic lime mortar would be very liable to fail, and, in fact, could not be expected to stand such an adhesional or tensional stress; but, as brickwork set in hydraulic mortar will fail under a compression of 400 lbs. per square inch, the factor of safety

$$= \frac{400}{81\cdot\dot{6}} = 4\cdot 9 \text{ nearly}$$

Therefore, although it would be sufficiently strong to resist compression, it would fail by its adhesive and tensile resistance being insufficient, and the lower part, at least, of such wall would be wisely built in cement.

Thicknesses of Walls.—The thickness of external and party walls is required by the Model Bye-Laws to be built in accordance with the following regulations:—In every case the thickness prescribed is the minimum thickness, and the regulations only apply to walls built of good bricks, not less than 9 inches long, or of suitable stone, or other blocks of hard and incombustible substances, the beds or courses being horizontal.

Dwelling-Houses.

Height up to 25 ft.	Length up to 30 ft. From base to top of wall 9 in.		Length unlimited. Wall below topmost storey $13\frac{1}{2}$ in. Remainder 9 in.
Height up to 30 ft.			Length unlimited. Below topmost storey $13\frac{1}{2}$ in. Remainder 9 in.
Height up to 40 ft.	Length up to 35 ft. Below topmost storey $13\frac{1}{2}$ in. Remainder 9 in.		Length unlimited. One storey 18 in. Rest of wall below topmost storey $13\frac{1}{2}$ in. Remainder 9 in.
Height up to 50 ft.	Length up to 30 ft. One storey 18 in. Rest of wall below topmost storey $13\frac{1}{2}$ in. Remainder 9 in.	Length up to 45 ft. Two storeys 18 in. Remainder $13\frac{1}{2}$ in.	Length unlimited. One storey 22 in. One storey 18 in. Remainder $13\frac{1}{2}$ in.
Height up to 60 ft.	Length up to 45 ft. Two storeys 18 in. Remainder $13\frac{1}{2}$ in.		Length unlimited. One storey 22 in. Two storeys 18 in. Remainder $13\frac{1}{2}$ in.
Height up to 70 ft.	Length up to 45 ft. One storey 22 in. Two storeys 18 in. Remainder $13\frac{1}{2}$ in.		Length unlimited. Wall to be increased $4\frac{1}{2}$ in. in each of the storeys below the uppermost two storeys.
Height up to 80 ft.	Length up to 45 ft. One storey 22 in. Three storeys 18 in. Remainder $13\frac{1}{2}$ in.		Length unlimited. Wall to be increased $4\frac{1}{2}$ in. in each of the storeys below the uppermost two storeys.

DWELLING-HOUSES—*continued.*

Height up to 90 ft.	Length up to 45 ft. 26 in. one storey; 22 in. for the next storey. Three storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in. in each of the storeys below the uppermost two storeys.
Height up to 100 ft.	Length up to 45 ft. One storey 26 in.; 22 in. for two storeys. Three storeys 18 in. Remainder 13½ in.		Length unlimited. Wall to be increased 4½ in. in each of the storeys below the uppermost two storeys.

In the case of a wall exceeding 60 feet in height and 45 feet in length, or of a storey exceeding in height sixteen times the thickness prescribed for its walls, or of a wall below that storey, the increased thickness may be confined to piers properly distributed, of which the collective widths amount to one-fourth part of the length of the wall. The width of the piers may, however, be reduced, if the projection be proportionately increased so that the horizontal sectional area is not diminished, but the projection must in no case exceed one-third the width of the pier.

If any storey exceed in height sixteen times the thickness prescribed for its walls, the thickness of the external and party walls throughout that storey must be increased to one-sixteenth of the height, and the thickness of the external and party walls of the lower storeys shall be proportionately increased, subject to the above provision as to the use of piers. All external or party walls must be at least 13½ inches in thickness, if the storey exceed 10 feet in height.

WAREHOUSE OR PUBLIC BUILDINGS WALLS.

Height up to 25 ft.			Length unlimited. Base 13½ in.
Height up to 30 ft.		Length up to 45 ft. Base 13½ in.	Length unlimited. Base 18 in.

WAREHOUSE OR PUBLIC BUILDINGS WALLS—*continued.*

Height up to 40 ft.	Length up to 35 ft. Base 13½ in.	Length up to 45 ft. Base 18 in.	Length unlimited. Base 22 in.
Height up to 50 ft.	Length up to 30 ft. Base 18 in.	Length up to 45 ft. Base 22 in.	Length unlimited. Base 26 in.
Height up to 60 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Base 26 in.
Height up to 70 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Thickness from the base to within 16 ft. of top to be decreased by 4½ in.
Height up to 80 ft.		Length up to 45 ft. Base 22 in.	Length unlimited. Ditto.
Height up to 90 ft.		Length up to 45 ft. Base 26 in.	Length unlimited. Ditto.
Height up to 100 ft.		Length up to 45 ft. Base 26 in.	Length unlimited. Ditto.

The thickness of these walls may be dealt with by the substitution of piers similarly as for dwelling-houses, except that the storeys must not exceed in height fourteen times their thickness, and the collective width of the piers must be one-fourth the length of the wall.

A similar provision is also made as to thickness of walls, but in this case the thickness must be one-fourteenth the height of the storey instead of one-sixteenth as for dwelling-houses, and the least thickness for walls must be, as before, 13½ inches for storeys over 10 feet high.

The varying thicknesses of warehouse walls must be as follows:—

At the top, and for 16 feet below, it must be 13½ inches, and the parts between the base and 16 feet below the top must be built solid throughout the space between straight lines drawn on each side of the wall, and joining the thickness

at the base to the thickness at 16 feet below the top. In walls not exceeding 30 feet in height, the walls of the topmost storey may be 9 inches thick if the height does not exceed 10 feet.

Cross walls, which may be deemed return walls for determining the length of external or party walls, shall be of two-thirds the minimum thickness prescribed for similar external or party walls, provided they are built of bricks or other suitable materials, as before described, but must in no case be less than 9 inches thick. If, however, such cross wall support a superincumbent external wall, the whole of the cross wall must be of the same thickness as an external wall of similar length and height for the same class of building.

Walls not built of the materials previously specified must be built with a greater thickness, as follows :—

If built with clunches of bricks or other burnt or vitrified material, or of flint work (the beds or courses not being horizontal), the thickness must be one-third greater than for walls of a similar height, length, and class when built of brick.

If built of other suitable material, or of a combination of brickwork and flintwork in which the brickwork is equal to one-fifth of the entire cubic content of the wall, and is properly distributed in piers and horizontal courses, or of half-timber work, it may be of the thickness prescribed for a wall built of bricks, and shall be otherwise similar to walls of the same height, length, and class.

RETAINING WALLS.

Definition.—Walls built to retain masses of water or earth are known as retaining walls, and are classified as follows :—Those made to support (1) the pressure of water are termed dams ; (2) to keep in safe equilibrium masses of earth, thus preventing sliding action, are known as revetment walls. A breast wall is a particular kind of revetment wall, constructed simply to protect from the weather a freshly exposed surface of a cutting, and when the latter is such as

to be capable of standing by itself if protected from the weather.

Conditions of Stability.—All retaining walls must satisfy the three conditions given previously for the stability of walls in uncemented blocks.

DAMS.

Pressure of Fluids.—The laws of fluid pressure state that the pressure at any part is directly as the height of a vertical

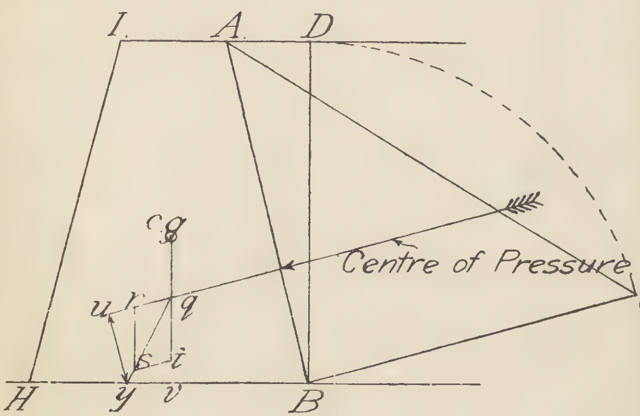


Fig. 114.

column of water above that part, and is perpendicular to the surface pressed against. Thus, against any surface as *A B*, in figure 114, the intensity of pressure varies from zero at *A* to the height of the vertical column of fluid upon *B*, and the total pressure for a unit of length is the weight of the triangular prism of water, of which *A B C* is the section.

Against a sloping line in a vertical plane, containing *A B C* as *A B*, figure 114, the pressure varies, as the ordinates between *A B* and *A C* from *A* to *C*; the maximum

pressure at B being equal to the vertical column of the fluid directly above. Let $B\ C$ be constructed at right angles to $A\ B$, and equal to $B\ D$; then the pressure for a unit of length is the weight of the triangular prism of water of which $A\ B\ C$ is the section. In the diagram $q\ r$ represents the pressure of the water, and $q\ t$ the weight of the wall.

The line of the centre of pressure will pass through the centre of gravity of the triangular prism, and the direction of the pressure is normal to the surface pressed against (as shown in figure 114).

REVETMENT WALLS.

Design.—In designing revetment walls it is necessary to determine (1) the plane of rupture; (2) the maximum horizontal thrust; and, after which, it is simplest to assume dimensions, and then test same as to the necessary conditions of stability.

Proposition for Stability.—The calculations for stability of all revetment walls are based upon the following proposition:—The moment of the effective mass of wall acting vertically at its centre of gravity, multiplied by the perpendicular distance from the intersection of the resultant pressure and base (let this be named y) equals the horizontal component of sliding pressure of earth, multiplied by the perpendicular distance from y, this latter value is equal, in cases where the retained earth is level with the top of the retaining wall, to the $\frac{h}{3}$.

Let t equal thickness of base of wall. Then for safe equilibrium using diagram, figure 115.

Moment of retaining mass = Moment of sliding wedge-shaped earth mass.

$$W \times vy = P \times \frac{h}{3}$$

$$\text{that is } W \times \frac{t}{6} = P \times \frac{h}{3}$$

in the diagram let qt = W, and qr = P, then

$$qt \times \frac{t}{6} = qr \times \frac{h}{3}$$

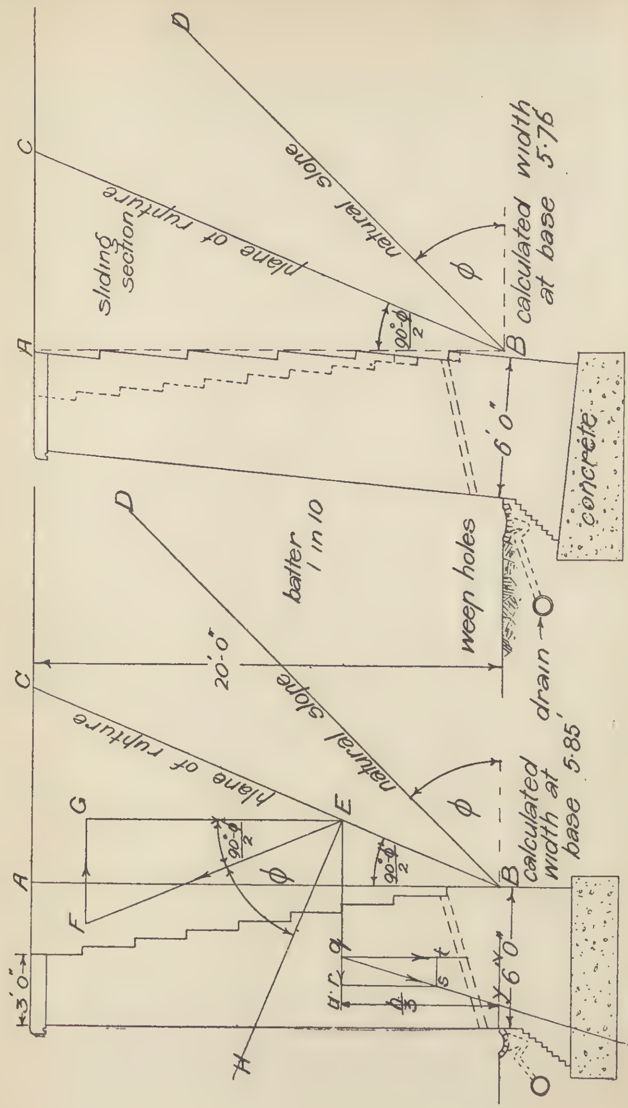


Fig 115

Fig. 116

The value of the effective retaining mass of wall is as follows:—(1) In rectangular vertical retaining walls, it is the weight of the mass of the wall; (2) in retaining walls with sloping backs, as in figure 117, the sum of the weight of the mass of wall and earth on the wall side of the vertical plane *A B*; (3) in leaning retaining walls, as shown in figure 118, the mass of wall, minus weight of the earth, which would fill *A B K*, because if this space were occupied by earth, its weight would be supported by the earth beneath

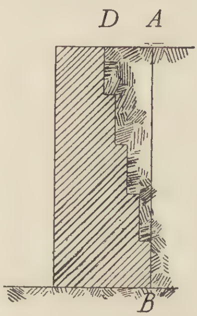


Fig. 117.

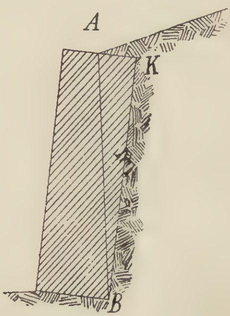


Fig. 118.

it exerting a pressure vertically upwards sufficient to sustain the weight of that triangular prism of earth.

Plane of Rupture.—It has been established by Coulomb, Poncelet and others, that earth in overturning a wall moves forward in a wedge-shaped mass, by sliding down some plane of rupture (as shown in *B C*, figure 115), which bisects the complement of the angle of repose *B D* starting from the base of the back of the wall. The earth *D B A*, in figure 117, may be considered as acting with the mass of the wall, and by gravity to equilibrate any earth tending to slide.

If the earth were not retained, the section *A B D* (figure 115) would particle by particle slip away; but the resistance offered by the friction of the earth and the back of the retaining wall retard this tendency, and it is found by

experiment that the part that would have the tendency to first break away and overturn the wall would be the section *A B C*.

Maximum Horizontal Thrust.—The sliding wedge-shaped mass of earth indicated by *A B C* may be considered to be kept in equilibrium by the friction of the earth, the direction of which force is at an angle to the normal to the plane of rupture equal to the angle of natural slope; this is shown as *E F* in figure 115, and the reaction of the revetment wall, which may be considered horizontal and acting at *E*, a height equal to $\frac{h}{3}$ from the base. The value of this component may be obtained graphically very easily, and in figure 115 *G E* is made equal to the weight of the sliding mass, then *F G* is equal to the weight of the wedge-shaped mass multiplied by the tan. $\left(\frac{90^\circ - \phi}{2}\right)$. This method is applicable to all revetment walls, whether retaining earth with horizontal or sloping (surcharged) tops. The leverage of the sliding earth masses of surcharged walls will always be greater than those with level tops.

Example I. (Fig. 115): Let it be required to support a bank of earth, 20 feet in height, weighing 120 lbs. per cubic foot, the angle of repose 45°, by a brick wall with a vertical face and a sloping, stepped back weighing 120 lbs. per cubic foot, the centre of pressure to fall one-sixth of the thickness from outer edge of wall.

Let ϕ = angle of repose of the earth.
t = thickness of base or bed joint of wall.
h = height of wall usually in feet.
w_1 = weight per cubic foot of retained earth.
$\overline{W}$ = total weight of retained earth.
w_2 = weight per cubic foot of wall material.
y = the leverage of the earth mass in terms of the height of the retaining wall.
z = the leverage of the wall in terms of t.
x = distance of centre of pressure to outer edge of wall.
p = pressure per unit of area,
then moment of mass of earth = moment of mass of wall.

$$W \tan. \frac{90 - \phi}{2} \, l y = (h \times l \times t \times w_2) \, z$$

$$\text{but } W = \frac{h^2 \tan. \frac{90 - \phi}{2}}{2} \, w_1$$

$$\therefore \quad \frac{h^2 \tan.^2 \frac{90 - \phi}{2} \, l \, w_1 \, y}{2} = (h \times l \times w_2) \, z \, t$$

$$\text{but } y = \tfrac{1}{3} h \text{ and } z = \tfrac{1}{3} t$$

$$\frac{h^2 \tan.^2 \frac{90 - \phi}{2} \, w_1}{6} = \tfrac{1}{3} w_2 \, t^2$$

Then for level-topped walls :—

$$t = \sqrt{\frac{h^2 \ \tan.^2 \frac{90 - \phi}{2} \, w_1}{2 \, w^2}}$$

$$\text{in this case } w_1 = w_2$$

$$\text{then } t = \sqrt{\frac{20^2 \times \tan.^2 22\tfrac{1}{2}^\circ}{2}}$$

$$\therefore \quad t = 5{\cdot}8578 \text{ feet.}$$

The nearest brick dimension is 6 feet, as shown in figure 115. To determine maximum pressure on bed joint—

$$p \times \text{area pressed} = \text{normal pressure on bed joint.}$$

$$p \times \text{area pressed} = \text{weight of wall.}$$

$$p \times 3 \, x \, l = h \, l \, t \, w_2$$

$$p \times 3 \times \frac{t}{6} = 20 \times t \times 120$$

$$p = 4{,}800 \text{ lbs. per square foot.}$$

$$p = 33\tfrac{1}{3} \text{ lbs. per square inch.}$$

$$\text{but maximum pressure} = 2p = 66\tfrac{2}{3} \text{ lbs. per square inch.}$$

Example II. (Fig. 116): Let it be required to support a bank of earth 20 feet in height, weighing 120 lbs. per cubic foot, the angle of repose 45°, by a brick wall, with a batter on face of 1 in 10, and back approximately vertical and weighing 120 lbs. per cubic foot, the centre of pressure to

intersect the base, so that the maximum pressure does not exceed $\frac{400}{6}$ lbs. per square inch. Let the wall be supposed to act with a leverage of $\frac{5}{12}t$.

The moment of mass of earth = Moment of mass of wall.

$$W \tan. \frac{90 - \phi}{2} l y = \left(h \frac{t + t - \frac{h}{10}}{2} l w_2\right) z$$

$$\frac{h^2 \tan.^2 \frac{90 - \phi}{2} l w_1 y}{2} = \left(h \times \left(t - \frac{h}{20}\right) \times l \times w_2\right) z$$

but $y = \frac{1}{3} h$ and $z = \frac{5}{12} t$

$$\frac{h^3 \tan.^2 \frac{90 - \phi}{2} w_1}{6} = 20 \times (t - 1) \times 120 \times \frac{5}{12} t$$

$$27{,}451 = 1{,}000\, t^2 - 1{,}000\, t$$

$$t^2 - t = 27 \cdot 451.$$

$$t^2 - t + \tfrac{1}{2}^2 = 27 \cdot 7$$

$$t - \tfrac{1}{2} = 5 \cdot 26$$

$$t = 5 \cdot 76$$

The nearest brick dimension is 6 feet, as shown in figure 116. As the earth in this case is of the same weight as the brickwork, the back of the wall might be economically sloped, as shown in figure 116 by dotted lines.

To determine maximum pressure on bed joint—

$p \times$ area pressed = normal pressure on bed joint.

$p \times$ area pressed = weight of wall.

$$p \times 3\,x\,l = h \times l \times \text{average } t \times w_2$$

then x can be calculated or measured from the drawing, and equals ·81 feet.

$$p \times 3 \times \cdot 81 = 20 \times \frac{5 \cdot 76 + 3 \cdot 76}{2} \times 120$$

$p = 4{,}701$ lbs. per square foot.

$p = 32 \cdot 647$ lbs. per square inch.

but maximum pressure $= 2\,p = 65 \cdot 29$ lbs. per square inch.

EXAMPLE III.: Let it be required to sustain a bank of earth 20 feet in height, angle of surface slope 30°, angle of

repose 45°, weighing 120 lbs. per cubic foot, by a retaining wall with a vertical face, and a sloping stepped back in brickwork, weighing 120 lbs. per cubic foot, the centre of pressure to fall one-sixth of the thickness from the outer edge of bed joint. Let the earth encroach beyond the theoretical back $A\ B$ a distance of $\frac{h.}{6}$ Then from figure 119—

$$A\ B = h + \frac{h}{6}\tan.\ \alpha = 20 + \frac{20}{6}\tan.\ 30^\circ = 21{\cdot}92, \text{ say } 22 \text{ feet.}$$

Moment of mass of earth = Moment of (mass of wall + mass of earth on top of wall).

$$F\ G \times \text{leverage} = (h \times l \times t) + \frac{\frac{h}{6} \times 2}{2} \times w_2 \times 2$$

$$\text{but } F\ G = \frac{A\ B\left(\dfrac{A\ B \times \sin.\frac{90^\circ - \phi}{2} \times \sin.\ 90^\circ + \alpha}{\sin.\ B}\right)}{2}\ w_1 \tan.\ \frac{90^\circ - \phi}{2}$$

$$\text{and leverage} = \frac{A\ D}{3} = \frac{C\ D \cot.\ \frac{90^\circ - \phi}{2}}{3}$$

$$\therefore\ F\ G \times \text{leverage} = \frac{A\ B\left(\dfrac{A\ B \times \frac{\sin.\ 90^\circ - \phi}{2} \times \sin.\ 90^\circ + \alpha}{\sin.\ B}\right)}{2}$$

$$w_1 \tan.\frac{90 - \phi}{2} \times \frac{\left(\dfrac{A\ B \times \sin.\frac{90^\circ - \phi}{2} \times \sin.\ 90^\circ + \alpha}{\sin.\ B}\right)\cot.\ \frac{90^\circ - \phi}{2}}{3}$$

$$\therefore\ \frac{A\ B\left(\dfrac{A\ B \times \sin\ \frac{90^\circ - \phi}{2} \times \sin.\ 90^\circ + \alpha}{\sin.\ B}\right)^2}{6} w_1 = (20\ t + 3\tfrac{1}{3})\ 120 \times \tfrac{1}{3}\ t$$

$$\frac{22\left(\dfrac{22 \sin.\ 22\frac{1}{2}^\circ \times \sin.\ 120^\circ}{\sin.\ 37\frac{1}{2}^\circ}\right)^2 120}{6} = 800\ t^2 + 133\tfrac{1}{3}$$

$$63117 = 800\ t^2 + 133\tfrac{1}{3}\ t$$
$$= 8{\cdot}8 \text{ feet nearly.}$$

The nearest brick dimension is 9 feet, as shown in figure 119.

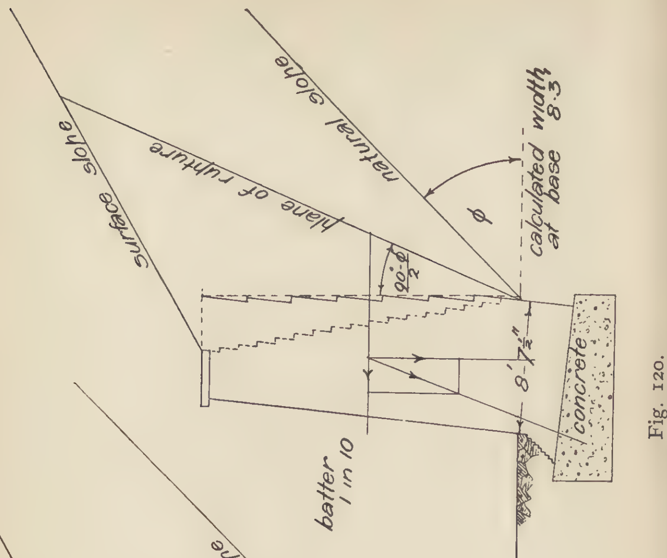


Fig. 120.

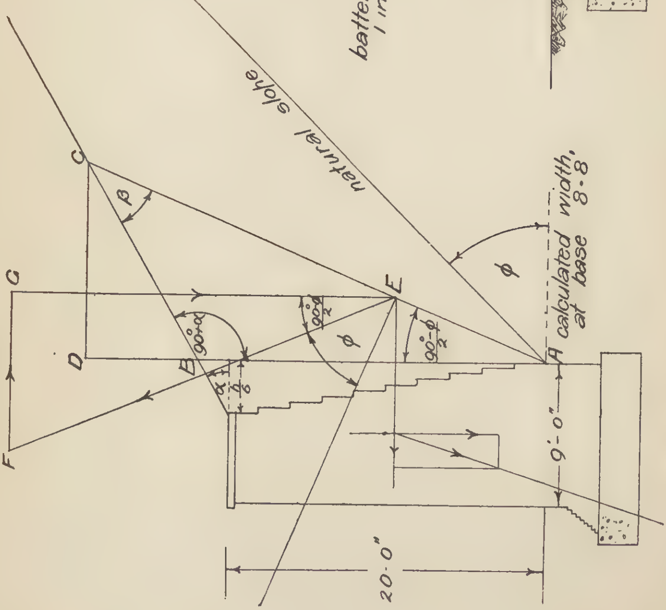


Fig. 119.

To determine maximum pressure on bed joint—

$$p \times \text{area pressed} = \text{normal pressure on bed joint.}$$
$$p \times \text{area pressed} = \text{weight of (wall + earth over wall).}$$
$$p \times 3 \times x \times l = h \times l \times t \times w_2 + 3\tfrac{1}{3}\, w_1\, l$$
$$p \times 3 \times \frac{t}{6} = 20 \times t \times 120 + 3\tfrac{1}{3} \times 120$$
$$p \times 3 \times \frac{8 \cdot 8}{6} = 20 \times 8 \cdot 8 \times 120 + 3\tfrac{1}{3} \cdot 120$$
$$p = \frac{4800 \times 8 \cdot 8 + 800}{8 \cdot 8}$$
$$p = 4890 \cdot 9 \text{ lbs. per square foot.}$$
$$p = 33 \cdot 9 \text{ lbs. per square inch}$$

but maximum pressure $= 2\,p = 67 \cdot 8$ lbs. per square inch.

Example IV.: Let it be required to sustain a bank of earth 20 feet in height, angle of surface slope 30°, angle of repose 45°, weighing 120 lbs. per cubic foot, by a retaining wall with a batter on face of 1 in 10, back approximately vertical, and weighing 120 lbs. per cubic foot, the centre of pressure to intersect the base so that the maximum pressure does not exceed $\frac{400}{5}$ lbs. per square inch. Let the wall be supposed to act with a leverage of $\frac{5}{12}\,t$. Let the earth encroach beyond the theoretical back A B a distance of $\frac{h}{6}$.

Moment of mass of earth = Moment of mass of wall.

The formula and the value in this case is the same as in Example III.—

$$\therefore\ 63117 = \left[(h \times l \times \text{average } t \times w_2) + \left(\frac{h}{6}\frac{\times 2}{2}\, w_1\right)\right] z$$

$$,, \quad = \left[\left(20 \times 1 \times \frac{t + t - \frac{h}{10}}{2} \times 120\right) + \left(\frac{\frac{20}{6} \times 2}{2}\ 120\right)\right] \tfrac{5}{12}\, t$$

$$,, \quad = \left[\ 2400\, t - 2000\ \right] \tfrac{5}{12}\, t$$

$$63117 = 1000\, t^2 - 833\tfrac{1}{3}\, t$$
$$t^2 - \tfrac{5}{6}\, t = 63 \cdot 117$$
$$t^2 - \tfrac{5}{6}\, t + (\tfrac{5}{12})^2 = 63 \cdot 117 + 1 \cdot 7$$
$$t - \tfrac{5}{12} = \sqrt{63 \cdot 28}$$
$$t = 8 \cdot 316 \text{ feet.}$$

The nearest brick dimension is 8 feet $7\frac{1}{2}$ inches, as shown in figure 120.

To determine the maximum pressure—

$$p \times \text{area pressed} = \text{normal pressure on bed joint.}$$
$$p \times \text{area pressed} = \text{weight of (wall + earth over wall).}$$
$$p\,3\,x\,l = (h \times l \times \text{average } t \times w_2) + 3\tfrac{1}{3}\,w_1\,l$$
$$p\,3\,x = (h \times \text{average } t \times w_2 + 3\tfrac{1}{3}\,w_1$$
$$p \times 3 \times 1{\cdot}089 = 20 \times \frac{8{\cdot}316 + 6{\cdot}316}{2} \times 120 + 3\tfrac{1}{3} \times 120$$
$$p = 5496{\cdot}8 \text{ lbs. per square foot.}$$
$$p = 38{\cdot}17 \text{ lbs. per square inch.}$$
$$\text{but maximum pressure} = 2\,p = 76{\cdot}34 \text{ lbs. per square inch.}$$

Generally.—Cuttings through clay swell if exposed to the air, and exert a force on the back of the wall which is difficult to determine. The thickness of the latter must be ascertained by experience.

In calculating for retaining walls, the angle of repose of the earth to be supported must be either known or determined by experiment (the earth being in that state in which by proper drainage it will remain), likewise the weights of the different materials. The former is given on page 230, the latter on pages 170 and 222.

Should the retained earth be such that when saturated with water it is practically mud, the retaining wall must be calculated as a dam to resist fluid pressure. The materials usually employed are concrete, brick, and masonry, thoroughly good bond being important in both of the latter.

The backs should be left rough or built in steps, and a layer of loose stone at least 12 inches in thickness, gravel or other porous material to afford a passage of water to the weep holes, should, in retentive soils, be packed up behind the walls, and weep holes not less than 7 square inches in sectional area placed along the bottom, from 5 to 10 feet apart; and in the case of retentive soils, one weep hole to every 4 square yards of face. The weep holes must be

connected to a surface drain to protect the foundations and footings, as shown in figures 115 and 116. In the section of wall usually adopted in practice, the thickness for about one-third the height from the base, is made equal to $\frac{h}{3}$ to $\frac{h}{4}$, and is reduced towards the top in regular offsets at the back.

The face is generally made to batter from 1 in 6 to 1 in 10. Too great a batter in a retaining wall is not desirable, as the wet gets into the joints, and tends to destroy the wall, unless they are pointed with cement.

A retaining wall with a batter of 1 in 10 can be bonded easily into an adjacent wall with a vertical face without inconveniently thickening the joints.

A batter is desirable, as it economically adds to the stability of the wall, and in the event of any slight outward displacement, the wall is not rendered apparently unsafe, as would be the case with a vertical wall.

Tall Piers.—The height of a pier in brickwork above any horizontal section should not exceed twelve times the least dimension of that section. The area of the base of such piers should be proportioned to the pressure they have to resist. For economy in labour the sides of the piers are usually carried up vertically and have the same sectional area at top as at the bottom, that is, they have an excess of strength and therefore of material. For perfect and economical construction the horizontal sections of a pier at any part should be proportioned to the pressure upon them. It would only be in the case of very tall piers supporting very heavy loads that it would be economical to design the piers to the theoretical sections, but if the piers are sufficiently large to build hollow then the theoretical section may be kept and built to with economy.

Example I.: Let it be required to support a load of 50 tons at a height of 30 feet on a brick pier approximately

square, the safe load on the brickwork being taken as 6 tons per superficial foot, and the weight of brickwork 112 lbs. per cubic foot.

$$\text{The area of the top course} = \frac{\text{total load}}{\text{safe load}}$$

$$= \frac{50}{6} = 8\tfrac{1}{3} \text{ super feet.}$$

Let A = area of required base

P = area of top base

r = ratio of increase of each block over the block above.

$R = (1 + r)$

n = number of unit blocks counting from the top

then $A = P\,R^n$.

Consider blocks of $1' \times 1' \times 1'$ to weigh 112 lbs.

$$\left.\begin{matrix}\text{then area of the lower block required to}\\ \text{support itself}\end{matrix}\right\} = \frac{\text{weight of brickwork}}{\text{safe load}}$$

$$= \frac{112}{6 \times 2240} = \frac{1}{120}$$

$$\therefore r = \frac{1}{120} \text{ and } R = \left(1 + \frac{1}{120}\right) = \frac{121}{120}$$

$$A = P\,R^n$$

$$= \frac{25}{3}\left(\frac{121}{120}\right)^{30}$$

$$= 10{\cdot}69 \text{ square feet.}$$

The top of pier has an area of $8{\cdot}\dot{3}$ superficial feet, and the base of lowest course 10·69 superficial feet, and the area of the base of any intermediate block would be calculated by the same formula.

If it be required to build the sides of this pier vertical an increase in the area of the base would be necessary to support the increased mass to maintain the maximum pressure of 6 tons per superficial foot. The increased area may be obtained in the following manner:—

Let x = side of required vertical faced pier

x^2 = area of required vertical faced pier

A = area of computed pier

w = weight of brickwork per cubic foot

then $(x^2 - A)$ safe load $= x^2\,h\,w$ – weight of computed pier.

The content of computed pier may be obtained by the formula for the sum of a geometrical series, viz.—

$$\frac{P\,(r^n - 1)}{r - 1} = 282{\cdot}7 \text{ cubic feet}$$

$$\text{and the weight} = 282{\cdot}7 \times w = 282{\cdot}7 \times 112 = 31662$$

$$\therefore (x^2 - 10{\cdot}6 \times 2240 = x^2 \times 30 \times 112 - 31662$$

$$x^2\,(13440 - 3360) = 142464 - 31662$$

$$x^2 = \frac{110802}{9980}$$

$$= 11{\cdot}1 \text{ sup. feet sectional area of required pier.}$$

If a square pier, then $x = 3{\cdot}\dot{3}$ feet; the nearest brick dimensions would be $4\frac{1}{2}$ bricks, that is 3 feet $4\frac{1}{2}$ inches.

EXAMPLE II.: Let it be required to support a load of 1,000 tons at a height of 100 feet on a brick pier, the safe load on the brickwork being taken as 6 tons per superficial foot, and to be stressed to this amount at any horizontal section, and the weight of the brickwork as 112 lbs. per foot cube.

The dimensions of the pier at top to be 27′ 0″ × 8′ 0″

$$\therefore P = \frac{\text{total load}}{\text{safe load}} = \frac{1000}{6} = 166{\cdot}\dot{6} \text{ sup. feet}$$

$$\text{at } 20' \text{ down } A = P\,R^{20}$$

$$= 166{\cdot}\dot{6} \times \left(\frac{121}{120}\right)^{20} = 196{\cdot}68 \text{ sup. feet}$$

$$40' \text{ down } A = P\,R^{40}$$

$$= 166.\dot{6}\left(\frac{121}{120}\right)^{40} = 232{\cdot}19 \text{ sup. feet}$$

$$60' \text{ down } A = P\,R^{60}$$

$$= 166.\dot{6}\left(\frac{121}{120}\right)^{60} = 274{\cdot}11 \text{ sup. feet}$$

$$80' \text{ down } A = P\,R^{80}$$

$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{80} = 323{\cdot}6 \text{ sup. feet}$$

$$100' \text{ down } A = P\,R^{100}$$

$$= 166{\cdot}\dot{6}\left(\frac{121}{120}\right)^{100} = 382{\cdot}03 \text{ sup. feet.}$$

To obtain the varying thicknesses of the pier at each 20 feet in its height. Let the batter be taken as 1 in 25,

then commencing at the 100 feet level, the dimensions as shown in Figures 122 and 123 at—

100 feet level	=	$8{\cdot}0' \times 27{\cdot}0'$
80 ,, ,,	=	$9{\cdot}6' \times 28{\cdot}6'$
60 ,, ,,	=	$11{\cdot}2' \times 30{\cdot}2'$
40 ,, ,,	=	$12{\cdot}8' \times 31{\cdot}8'$
20 ,, ,,	=	$14{\cdot}4' \times 33{\cdot}4'$
0 ,, ,,	=	$16{\cdot}0' \times 35{\cdot}0'$

The thickness at the 100 feet level has already been obtained and is 3 feet, then at the 80′ level the thickness x may be obtained as follows:—

$$\begin{aligned}(\text{round of walls} - 4x)\,x &= \text{required area}\\ 76{\cdot}4x - 4x^2 &= 196{\cdot}68\\ x^2 - 19{\cdot}1x &= -\,49{\cdot}17\\ x^2 - 19{\cdot}1x + (9{\cdot}55)^2 &= 91{\cdot}212 - 49{\cdot}17\\ x - 9{\cdot}55 &= 9{\cdot}55 - 6{\cdot}48\\ x &= 3{\cdot}07\end{aligned}$$

Then determining the thicknesses at the other levels in a similar manner the thicknesses required as shown in Figure 123 will be as follows:—

100 feet level	$3{\cdot}0'$
80 ,, ,, ...	$3{\cdot}07'$
60 ,, ,, ...	$3{\cdot}35'$
40 ,, ,, ...	$3{\cdot}68'$
20 ,, ,, ...	$4{\cdot}09'$
0 ,, ,, ...	$4{\cdot}56'$

The area of spread for the footings and concrete may be determined as has been previously explained, the weight of the pier above the footings may be ascertained by the formula for the summation of a geometrical progression. As the brickwork would for practical reasons be built in parallel thicknesses there would be a loss in working from the top downwards by this formula, and similarly there would be a gain in working from the bottom upwards, the actual quantity may be taken as the arithmetic mean of

Fig. 122.

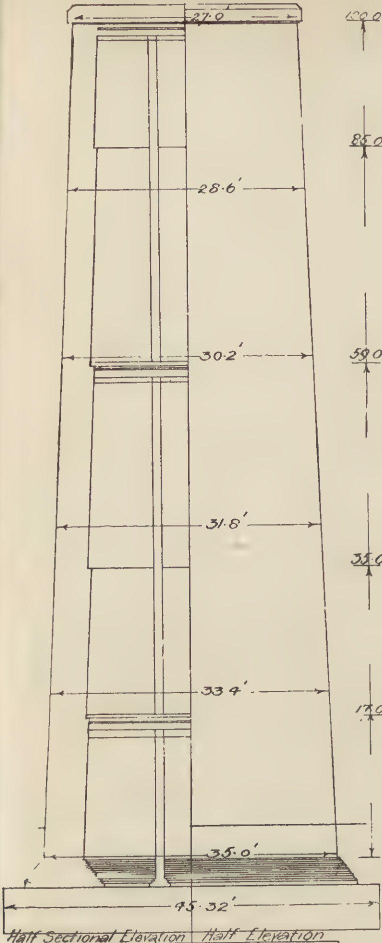


Fig. 123.

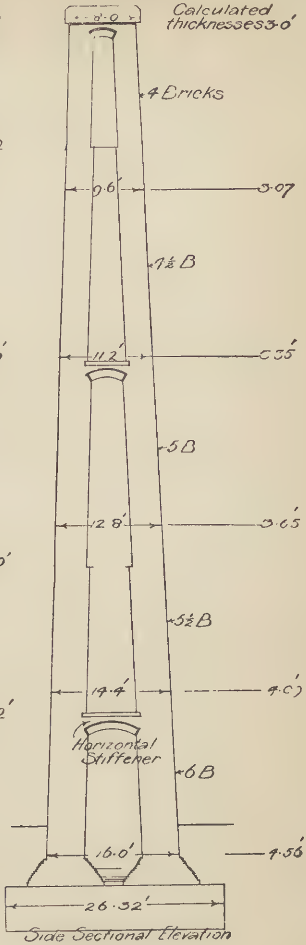
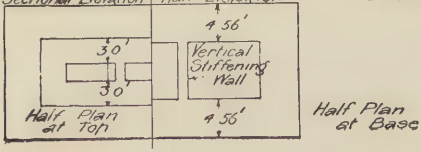


Fig. 121,



these two without any appreciable error. From the top downwards, let blocks 1 foot deep be taken.

$$S = \frac{A\ (r^n - 1}{r - 1}$$

$$= \frac{166 \cdot \dot{6}\left(\frac{121^{100}}{120} - 1\right)}{\frac{121}{120} - 1}$$

$$= 25641$$

From the bottom upwards:

$$S = \frac{A\ (1 - r)}{1 - r}$$

$$= \frac{382 \cdot 03\left(1 - \frac{120^{100}}{121}\right)}{1 - \frac{120}{121}}$$

$$= 26081$$

therefore the mean of these two is 25,861 cubic feet, and the weight will be 1,284·05 tons.

Figures 121, 122, and 123 show the construction of the pier with the necessary stiffening walls and arches.

Chimney Stacks.—Enclosed channels, formed usually in brickwork, to discharge (1) smoke, are termed smoke flues; (2) vitiated atmosphere, are termed foul air flues; a construction containing one or more vertical flues being known as a chimney stack.

Theory.—Air upon being heated ascends, its velocity being determined by the well-known kinematical formula $V^2 = 2gh$, and if the value of g be taken as 32, $V = 8\sqrt{h}$, and $h = Ht \times \cdot 002$, where H equals the height of column of heated air in feet, and t the excess in degrees Fahr., of column of heated air over external air.

Smoky Flues.—Theory points out that an increased velocity may be obtained by increasing the height or raising the temperature, and the greater the upward velocity the

less will be the probability of a down draught, the latter causing what is known as a smoky chimney, and it suggests that a flue with a small volume of air to rarify, with a comparatively great height, is more effective than an equal volume in a flue with a less height.

Prevention of Down Draughts.—To prevent down draughts no external chimney opening for the discharging of smoke

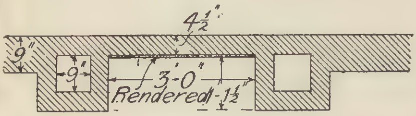


Fig. 124.

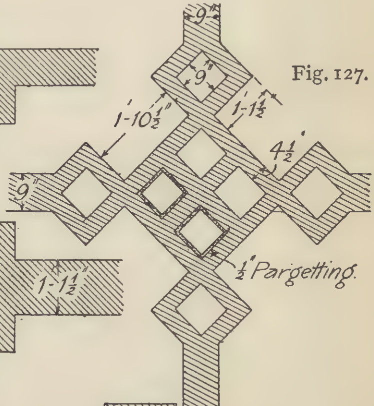


Fig. 127.

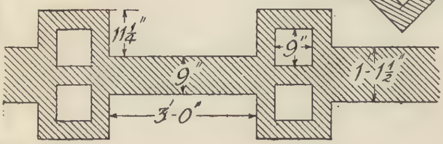


Fig. 125.

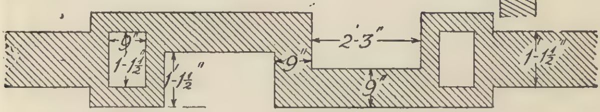


Fig. 126.

should have a lower level than any other similar flue exit in close proximity, and it is in addition preferable for this opening to be about 3 feet above any adjacent ridges or walls.

Care taken in this matter would to a large extent render unnecessary cowls and other expedients for the so-called "cure of smoky chimneys."

Flues.—The flues should be built with at least one bend with an internal angle of not less than 130°. They must be gradual and easy, so as to offer a minimum resistance to

the up current. Gusts of wind and down draughts are retarded by the bends in the flues; the same sectional area should be kept throughout till near the exit, when a small contraction in area is conducive to an increased velocity.

Classification of Smoke Flues.—The plans of chimneys may be arranged in three ways, viz.: (*a*) Back to back, as shown in figure 125; (*b*) side by side, or interlacing; (*c*) diagonally.

Figure 124 shows the first method, with 9 in. × 9 in. flues, with the backs made $4\frac{1}{2}$ inches in thickness, when, to comply with the Model Bye-Laws, they must be rendered. This arrangement is most usually adopted to curtail expense.

Figures 128 and 129, the usual arrangement of fireplaces and flues in the external walls of houses.

Figures 130 and 131 show an elevation and section of a system of flues back to back in a party wall. Figures 132 to 136 show the plan of the courses at each storey of this system.

The interlacing system, as shown in figure 126, is sometimes used in order that the projection into the room may be as small as possible; but it could not be adopted in party walls, except where both houses belong to the same property, as the flues would project beyond the centre line. The diagonal method, as shown in figure 127, is more particularly suitable for use in small rooms, where a fireplace near the centre of room would not be convenient. Angle fireplaces may be arranged with one or in groups of two, three or four at any one level.

Generally.—Every fireplace should have a separate flue, and in a stack the partition walls or withs must be smoke-proof. Any connection between flues causes smoky chimneys.

A grouping of flues in a building tends to economy and effectiveness.

The outer brickwork surrounding flues, to act effectively

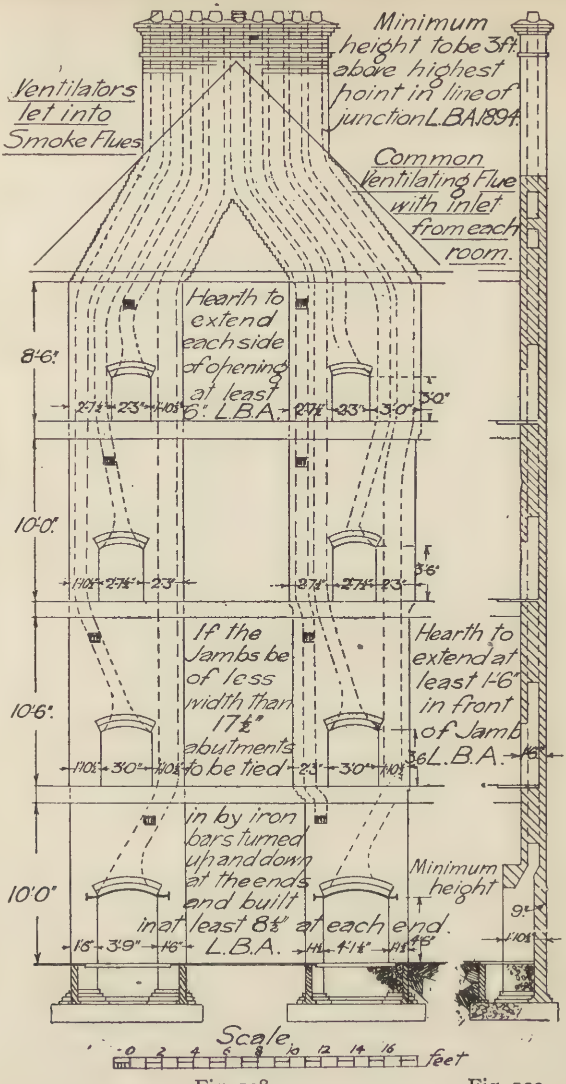


Fig. 128.

Fig. 129.

as a screen from the outer air, and as an efficient non-conductor of heat, is best where not less than 9 inches in thickness. The withs are usually half a brick thick, but great care must be exercised to have a thorough bond at the gathering over of the withs.

Chimney Bond.—The bonding in chimneys with $4\frac{1}{2}$ inch backs is most effectively accomplished by the use of Flemish bond; this method lends itself to the bricks of the withs of one course forming the face headers, and bats only being used on face in the alternate courses, as shown in figure 1049, *Elementary Course.* The use of English bond for $4\frac{1}{2}$ inch backs necessitates a considerable amount of cutting, thus causing the work to be weak and expensive.

Material for Flues.—The materials used for chimneys must be incombustible, durable, and sufficiently stable to resist external forces, such as wind pressure. Without the assistance of ties or any other special construction, brickwork best satisfies these conditions. For reasons, see chapter on Fire-resisting Constructions.

The following notes are based upon the requirements of the Model Bye-Laws, which are valuable as representing the product of considerable thought and vast experience:—

Dimensions of Flues.—Section 6 of the "Act for the Regulation of Chimney Sweepers and Chimneys," 1840, provides for the use of flues 14 in. × 9 in., or circular 12 inches diameter. There is but little doubt, however, that the use of a flue 9 inches square often prevents smoky chimneys, as on account of the smaller sectional area, a greater draught is created. Of late years 9 in. × 9 in. flues have been generally used as the standard dimensions for flues for ordinary purposes, 9 in. × 9 in. rectangular and 10 inch circular fireclay flues are largely used instead of the pargetted lining.

Fig. 130.

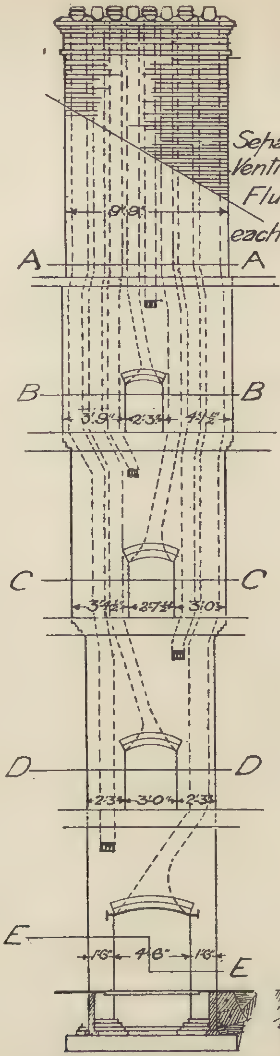
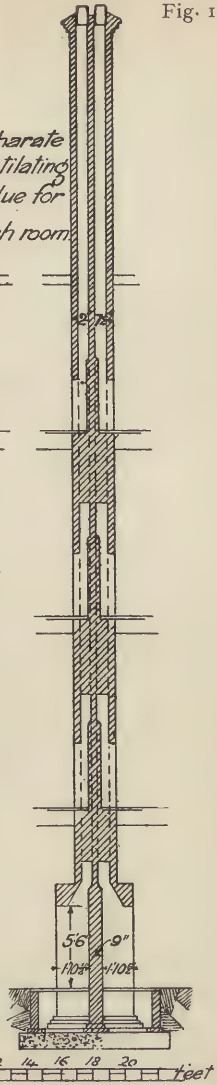


Fig. 131.



These make a clean lining, and the liability of the withs becoming imperfect is very much reduced.

Foundations for Chimneys.—The Model Bye-Laws provide that all chimneys must be built upon solid foundations with footings similar to those of the wall in which the chimney is built, or upon sufficient corbels of bricks or stone, or other incombustible substances, as in the case of a chimney commencing above a shop. This corbelling must not project more than the thickness of the wall below the corbel. The corbelling must be done properly, otherwise the centre of gravity of the mass will be brought dangerously near the face of the lower part of the wall, and there will be a tendency to overturn, and the fall of walls inwards at times suggests this as one reason among others for the direction of the fall.

Pargetting.—All flues must be pargetted as they are carried up, unless lined with a fireclay lining 1 inch thick, or the spandrel angles filled in with brickwork, or other incombustible material. The back or outside of all flues must be rendered, if it be less than 9 inches thick, unless it forms part of the outer face of an external wall. Pargetting is a rendering on the inside of the flue with ordinary lime mortar. This is to provide against the accumulation of soot in the joints, or of fire penetrating them. The outside of flue breasts should always be rendered, especially behind skirtings and beneath floors, where it is more necessary than elsewhere, owing to the close proximity of woodwork.

Thickness of Backs of Chimneys.—Every flue of a furnace, steam boiler, or close fire used for trade purposes, or of any cooking apparatus or range of an hotel, tavern, or eating-house, must be surrounded with brickwork not less than 9 inches thick for 10 feet above the floor level. The back of a chimney opening in a party wall used for a kitchen

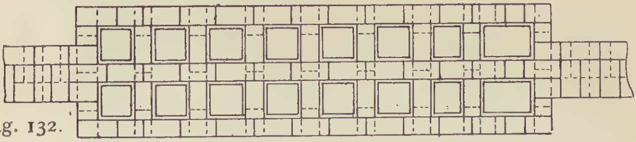


Fig. 132.

Section A.A.

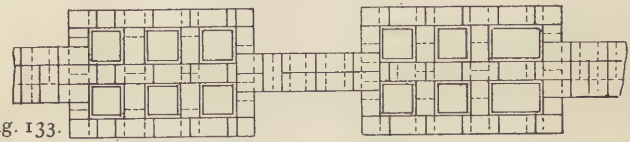


Fig. 133.

Section B.B

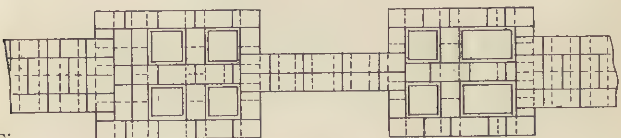


Fig. 134.

Section C.C

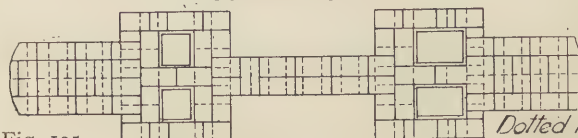


Fig. 135.

Section D.D.

Dotted lines show the alternate course

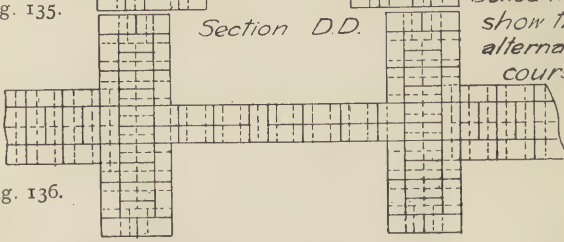
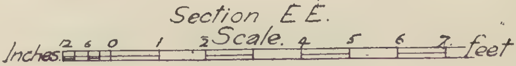


Fig. 136.

Section E.E.



range must be 9 inches thick for 6 feet above the chimney opening, and such thickness must be continued at the back of the flue; the backs of all other chimneys from the hearth up to a height of 12 inches above the opening must be at least $4\frac{1}{2}$ inches thick if in an external wall, and 9 inches thick elsewhere than in an external wall.

Support of Chimney Breasts above Opening.—A sufficient arch of brick or stone, or a bar of iron, must be built over the opening of every chimney, and, if the breast project more than $4\frac{1}{2}$ inches and the jambs be less than $13\frac{1}{2}$ inches, the abutments must be tied in with a wrought-iron chimney bar, 18 inches longer than the opening. In most cases the breasts project 9 inches or more, and, therefore, if the jambs are less than $13\frac{1}{2}$ inches, these chimney bars must be used, one for each brick in the horizontal thickness of the arch. The ends of chimney-bars should be caulked, *i.e.*, cut and turned up and down.

Width of Jambs.—The Model Bye-Laws require that the jambs must be at least 9 inches wide on each side of chimney opening, and the brickwork surrounding any flue not less than $4\frac{1}{2}$ inches thick.

Thickness of Brickwork on Upper Side of Flues.—Where flues make an angle less than 45° with the horizon, the brickwork of the upper side must be at least 9 inches thick. This is a necessary provision to secure safety from fire, as if the upper side were not very substantial, the ascending heat might be a considerable source of danger.

Least Height of Chimney Stacks above Roofs.—All chimneys must be carried up $4\frac{1}{2}$ inches least thickness to a height of not less than 3 feet above the highest point in the line of junction with the adjoining roof, flat, or gutter. It is, however, generally advisable to carry the chimney 3 feet above the ridge-line to prevent down draught.

Maximum Height of Chimneys.—The Model Bye-Laws fix the following as the height to which chimneys may be carried above the roofs in exposed situations, although it may be necessary to make them of somewhat less height:—They shall not be built higher above the adjoining roof, flat, or gutter, than six times the least width of the shaft at the highest point of junction, unless built with and bonded to another chimney shaft not in the same line with it, or otherwise made secure. This does not apply to factory chimneys, for which a special construction is necessary.

Fastenings in Walls of Flues.—No iron holdfast or metal fastenings may be driven nearer the inside of a flue than 2 inches.

Proximity of Woodwork to Flues.—The provisions as to the proximity of woodwork to flues are briefly as follows:—

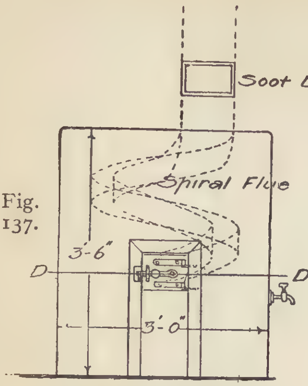
No woodwork must be built into walls or chimney breasts nearer than 12 inches from the inside of any flue, or under any chimney opening within 15 inches from the upper surface of the hearth. This relates to the insertion of timber beneath the back-hearth or chimney opening, and not, as might be supposed, to the lathing and bearers of the ceiling beneath the front hearth.

No wooden plug may be driven into any wall or chimney breast nearer than 6 inches to the inside of any flue or chimney opening.

No woodwork must be nearer the face of the brickwork or stonework about any flue or chimney opening than 2 inches if the brickwork be less than 9 inches thick, unless the brickwork be properly rendered as before described.

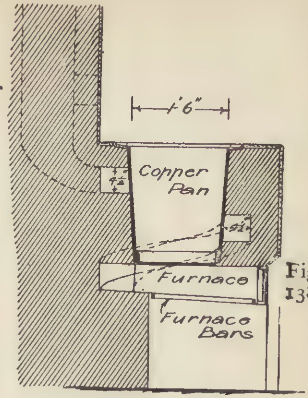
Openings into Flues.—Openings for ventilating valves into smoke flues must not be less than 9 inches from woodwork, and in practice such openings are usually placed about 12 inches below the ceiling-line.

Fig. 137.



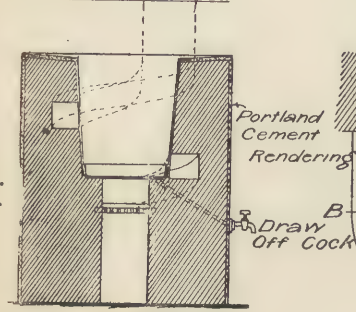
Front Elevation

Fig. 138.



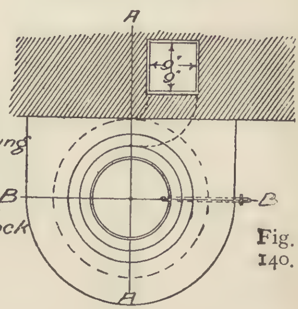
Section A A

Fig. 139.



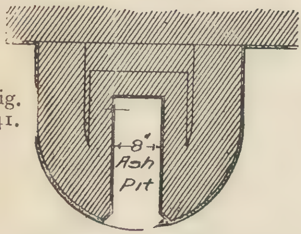
Section B B

Fig. 140.



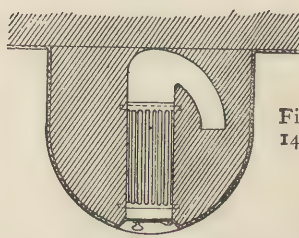
Plan

Fig. 141.

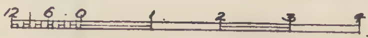


Section C.C.

Fig. 142.



Section DD

Scale  of Feet

Soot Doors.—If any interior angle in a flue be less than 130°, a soot door must be provided for cleaning. This is usually specified as 6 inches soot door and frame.

Proximity of Smoke Pipes to Woodwork.—No pipe used for conveying smoke or the products of combustion may be fixed at a distance less than 9 inches from any woodwork.

Copper.—Figures 137 to 142 show the construction of an ordinary domestic copper. In these arrangements large quantities of water are required to be heated with rapidity for the purposes of cleansing linen and for other domestic purposes. It is necessary that the copper pan should have a large heating surface. A furnace is constructed beneath the pan and with a spiral flue about it. Section C-C shows the outline of the lowest course, section D-D shows the section through the furnace, figures 138 and 139 show vertical section through the copper and figures 137 and 140 give the elevation and plan. The brickwork is externally rendered in cement to form a finish. A draw-off cock is shown to remove all water from copper pan when the latter is not in use. These draw-off cocks are frequently omitted, but there is then great difficulty in removing water from the copper pan, especially when the latter is hot, should a change of water be necessary. A soot door should be provided in the lowest part of the straight flue to facilitate the sweeping of the flue.

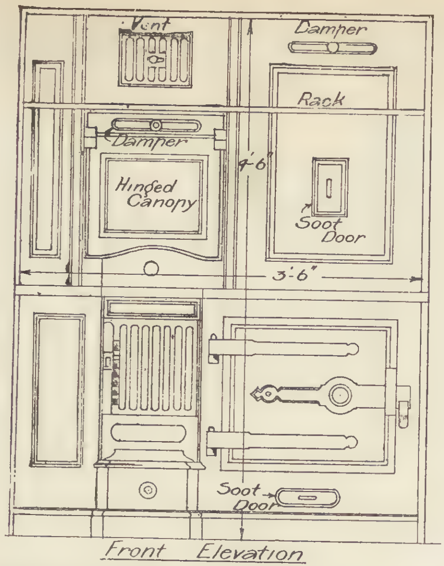
Range.—Figures 143 to 149 show the arrangements of the parts of a kitchen range of modern construction, and the setting. An oven and arched high pressure boiler is shown. Economy of fuel is provided for by having a small furnace and causing the heat from the latter to transverse as large a surface of the oven and boiler as possible before finally being conducted up the flue. In this arrangement there are two primary flues, one each for the boiler and the oven. Should the oven be required to be heated rapidly, the boiler damper

is closed and the oven damper opened; the heat then passes in the direction indicated by arrows, over the top of the oven, down the side, and is caused to pass towards the front of the oven by a thin iron partition marked L in the figure, and finally up the flue at the back of the oven. Thus four sides of the oven are directly exposed to the heat. The side adjacent to the fire is protected by a fire-brick. The heat in passing over the top of the oven renders the whole of the hot-plate available for cooking purposes. Should it be required to heat the boiler rapidly the damper is withdrawn, the heat then being induced to pass under and up the back of the boiler.

The boiler is frequently placed at the side of the furnace similarly to the oven, the arrangements for heating the boiler being then identical with that of the oven. The oven and boiler flues discharge into a common flue above the cover plate.

If an open fire is required, the portion of the hot plate marked Y-Y directly above the furnace is pushed back in the direction indicated by the arrows beneath the portion of the hot-plate in its rear. The flap marked "hinged canopy" is then raised, and two side wings withdrawn; the heat then passes directly up the boiler flue. The furnace bars revolve upon a pivot at their back edge so that their bottom may be raised or lowered to adjust the quantity required at any time, the bottom is kept in any desired position by a rack and pawl arrangement as shown in figure 148. For the efficient working of these ranges it is essential that the flues be kept thoroughly clean; for this purpose soot doors are arranged at every change of direction in the flues about oven and boiler. Figures 145 and 143 show plan and elevation of range complete; figure 147 shows the arrangement of the brickwork for seating the boiler and oven; figure 144 shows a similar sketch with the range front and hot-plate removed, and showing oven, boiler and furnace bars in position; figure 146 shows

Fig. 143.



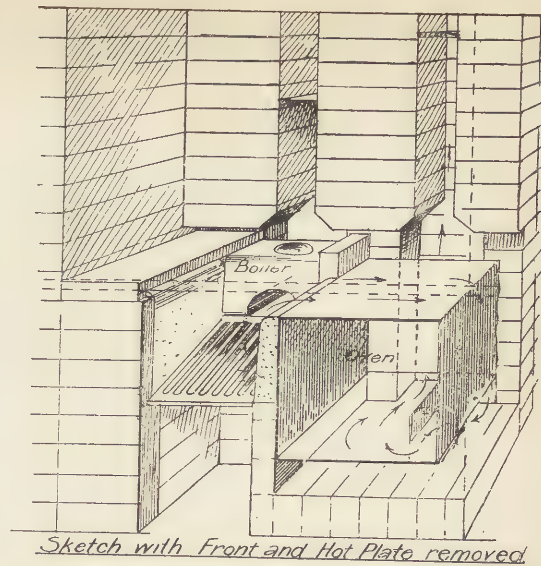


Fig. 144.

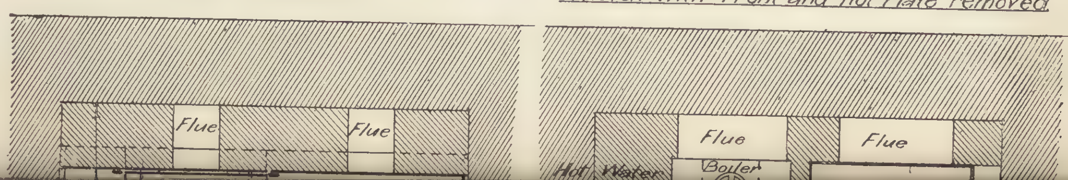


Fig. 145.

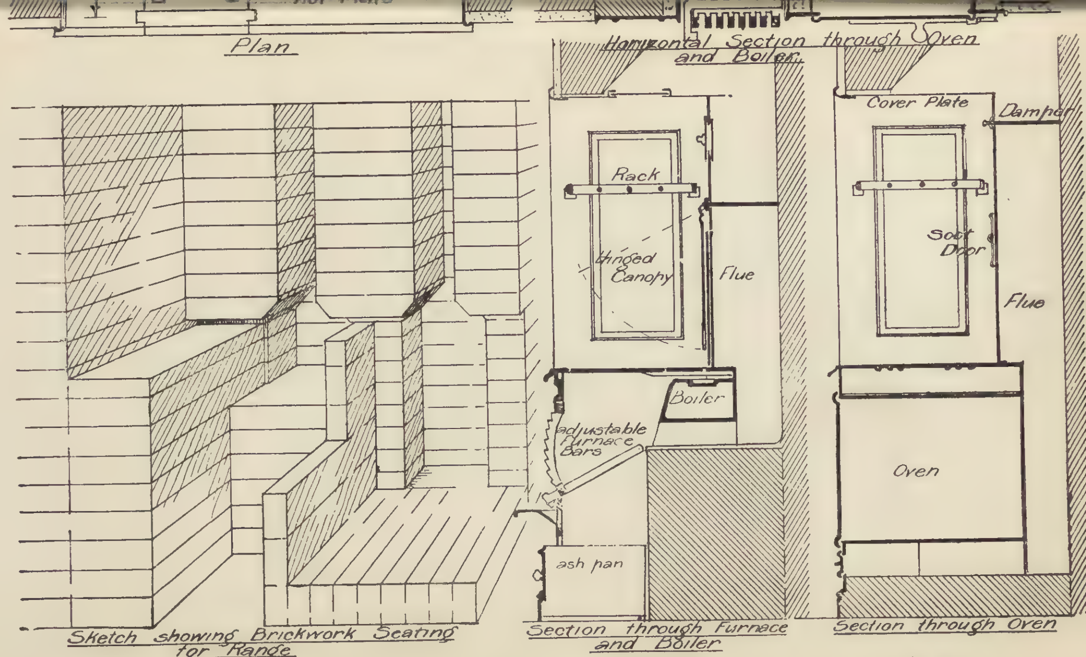


Fig. 147.

Fig. 148.

Fig. 149.

Figs. 143—149.

[*Between pages 268 and 269.*

horizontal section through furnace, oven and boiler; and figures 148 and 149 show vertical sections, one through oven, the other through furnace and boiler.

Register Grates.—For heating living rooms open grates are usually provided; these should be of the form known as slow combustion register grates. There are many varieties of these, subject to various patents, but the ordinary form is shown in figures 598 to 603 in the *Elementary Course.*

It consists of a cast iron frame and furnace bars, the back of the fire-basket being formed of purposely-made fire-bricks.

The requirements of these stoves are to obtain the maximum of heat with the minimum consumption of fuel and the most perfect combustion. In lighting, a rapid draught is required for a short time till the coal has ignited. To arrange for this a movable damper about the bottom of the fire-basket is provided, which when removed allows large quantities of air to pass through the fuel. When the coal has ignited the damper is placed in position, the supply of air is thus regulated and combustion takes place at a lower rate. The fire-brick back, to be efficient, must be at least three inches in thickness; this rapidly becomes red hot and thereby greatly assists in the more perfect combustion of the fuel. The fire-brick back is canopied over at the top in order to reflect the heat into the room while allowing the smoke to escape up the flue. The basket should be arranged as low as possible, not more than 2 inches above the hearth, so that the lower stratum of air in the room should be warmed. Figure 602, *Elementary Course*, shows the metal canopy, behind which is an iron flap known as the register, which is closed as shown when the grate is not in use, to prevent soot falling from the chimney into the room. In many cases the register is omitted and the canopy is hinged.

In setting these grates they should be placed in position

and built up solid about their sides; the upper portion of the back setting sloping downward as shown towards the register. The filling up between the top of the grate and the arch is omitted on the drawing to show chimney bar. Any neglect to completely fill up the sides and top of grate will result in a smoky fireplace. Figures 598 to 602, *Elementary Course*, show an ordinary marble mantelpiece in front of grate, also the construction of trimmer arch and hearth; and Figure 603, *Elementary Course*, shows the method of constructing hearth of concrete instead of using trimmer arch.

Proximity of Smoke Pipes to Woodwork.—No pipe used for conveying smoke or the products of combustion may be fixed at a distance less than 9 inches from any woodwork.

TALL CHIMNEY CONSTRUCTION.

In determining the dimensions of chimneys, the height is regulated by the draught required, and often to satisfy sanitary conditions, while the dimensions of the diameter is a question of wind pressure.

The following notes may be found useful, when designing a tall chimney.

Molesworth gives the following practical rules for chimneys:—

Let a = Area of fire-grate in square feet.
,, F = Quantity of coal consumed per hour in lbs.
,, h = Height of chimney in feet.
,, HP = Horse-power of engine (indicated).
,, A = Area of top of chimney in square inches.

$$\text{Then A} = \frac{15\ \text{F}}{\sqrt{h}} = \frac{100\ \text{HP.}}{\sqrt{h}} = \frac{180a}{\sqrt{h}}$$

and the velocity of the draught may be determined by the formula—

$1296\sqrt{\text{H}t}$ = velocity of draught in feet per hour,
when H = vertical height of chimney in feet above fire-grate,
and t = difference of heated air column over external air in degrees Fahrenheit.

The regulations of the London County Council require the following points to be observed :—

If square, the width must be one-tenth of the total height. If circular, the width must be one-twelfth of the total height. The batter is to be $2\frac{1}{2}$ inches in every 10 feet or an inclination of 1 in 48.

The brickwork must be at least $8\frac{1}{2}$ inches at the top and for 20 feet below, and the thickness of the brickwork must be increased $4\frac{1}{2}$ inches for every additional 20 feet of height measured downwards.

The fire-brick lining is to be additional to the thickness of the ordinary brickwork.

No cornice or other projection must stand out more than the thickness of the brickwork at the top.

Example.—Figures 150 to 155 illustrate a tall chimney complying with these regulations. Figure 150 shows half section and half elevation with the inlet flue and manhole for cleaning purposes, also the fire-brick lining and lining cover; this lining must be quite separate from the outer casing, with a clear space of at least 2 inches. In many cases bricks are projected from the lining into this clear space to nearly touch the outer casing; these prevent any deformation of the inner lining by guiding the expansion upwards. Foot irons are shown in the half section to admit of inspection and repairs. Figure 151 shows plan through flue and manhole. Figure 152 shows vertical section through flue. Figures 153 and 154 show plan through base and centre of shaft, and figure 155 shows enlarged detail of a cast-iron cap and cornice surmounting the whole. The dimension of flue at exit should not exceed the area of the exit of fire-brick lining. Tall chimneys were usually built in hydraulic lime mortar, but in a number of modern examples advantage has been taken of the superior tensile and adhesive resistances of Portland cement.

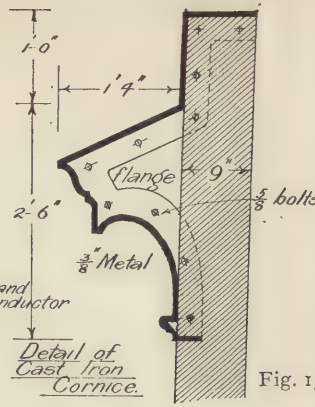


Fig. 155.

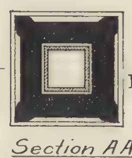


Fig. 153.

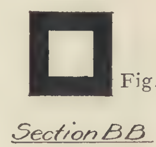


Fig. 154.

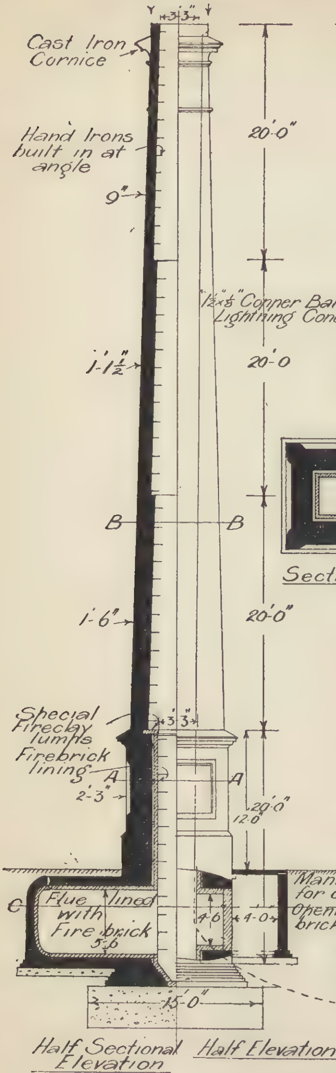


Fig. 150.

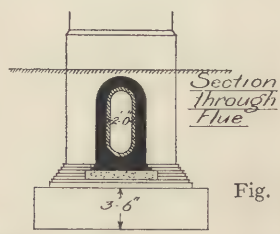


Fig. 152.

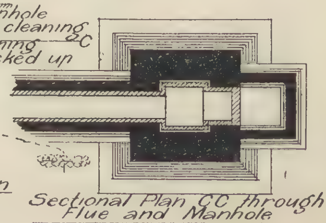


Fig. 151.

Caps are often of stone, but of late a great many have been made of cast iron, which is more economical and reliable than stone; the latter after fixing being subject to developing defects which, unless great skill and judgment are used, are liable to be overlooked.

Cramps when made of iron rust and corrode, and used in stone caps, often prove very ineffective, and hence should be of gun-metal.

In circular chimney shafts, where stone caps are used, continuous gun-metal rings are sometimes employed instead of cramps to bind the courses of stonework together.

The limiting position of the centre of pressure of the forces acting upon square and circular chimneys has already been dealt with.

The principal disturbing force acting on chimneys usually is wind pressure, 50 to 55 lbs. per square foot being the value usually computed for wind pressure to be resisted by the shaft.

In square chimneys, the area exposed to the force of the wind is the height multiplied by the width, that is the area of its diametral plane.

In circular chimneys the total pressure is the height multiplied by the width of the diametral plane by ·66 P; the reduced value of the wind pressure is due to the loss by slipping, which loss is about one third of its pressure. Tall chimneys in this country are built in brickwork set in hydraulic lime mortar composed of one of lime to two of sand. It being thought that cement mortar, though having much greater adhesive and tensile resistances than lime mortar, is subject to deterioration when exposed to the intense heat at the base of a chimney, and fails under a less wind pressure than those built at the base in lime mortar. The success of the Weber Co. ferro-concrete chimneys of late years in America and England tends to prove this to be erroneous, and that Portland cement mortar can safely

withstand temperatures up to 1500° Fahr. When this heat is exceeded fire-brick lining set in fire-clay should be used.

Determine the permissible safe wind pressure per square foot on a brick chimney circular section, as shown in figures 156 to 158 at each change of section. External diameter at top = 4′9″; thickness of brickwork 9″; increase of $4\frac{1}{2}$ inches in thickness each twenty feet from top, batter one in 48; weight of brickwork 112 lbs; centre of pressure to fall at Cp (figure 159) A Cp = $\frac{1}{4}$ A B from leeward edge; the distance from Cp to the centre of the section will be the leverage. The total value of the wind pressure against a chimney of circular section is the height multiplied by the width of the diametral plane multiplied by ·66 P. The value of P against a plane surface perpendicular to the wind being reduced on chimneys of circular section by the loss due to slipping, which is about one-third of its pressure.

There are two methods of calculation: First, ignoring the tensional and adhesional resistances of the mortar and considering each section as a block for the determination of the wind stress that would give with the mass of the wall a resultant pressure that would fall at a safe position in the section. This latter for the different sections is given before in this chapter. Secondly, by considering the shaft as a cantilever, and with the given required pressure to determine the stresses on the extreme edges. These stresses on any proposed shaft for safety must not exceed the safe tensional, compressional and adhesional values of the materials of construction.

A mortar tested at the Royal Testing Station, Berlin, between unperforated bricks gave an adhesive resistance of $21\frac{3}{4}$ lbs. per square inch, but the same mortar on perforated bricks gave an increased value of $61\frac{1}{2}$ lbs., nearly three times as great as on the perforated brick. Messrs. Custodis & Co., Westminster, have patented perforated

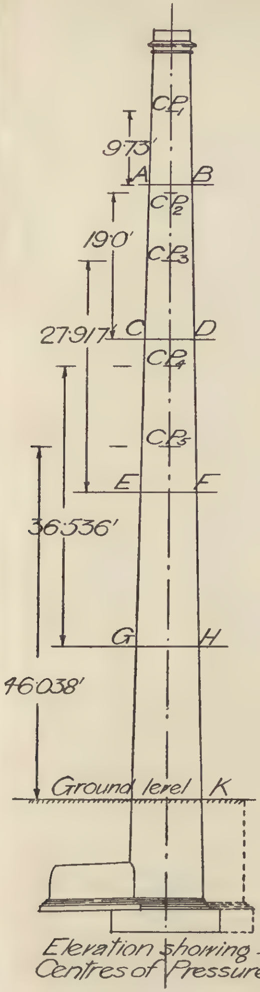


Fig. 156.

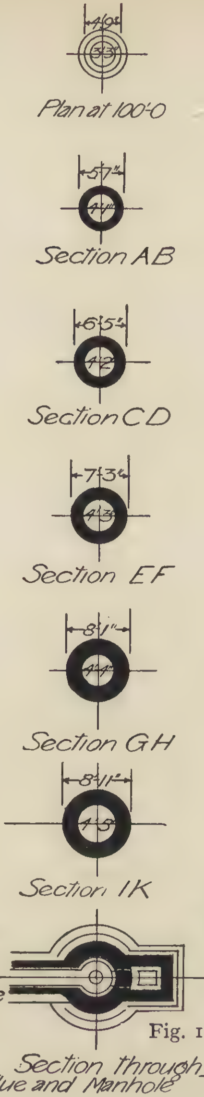


Fig. 157.

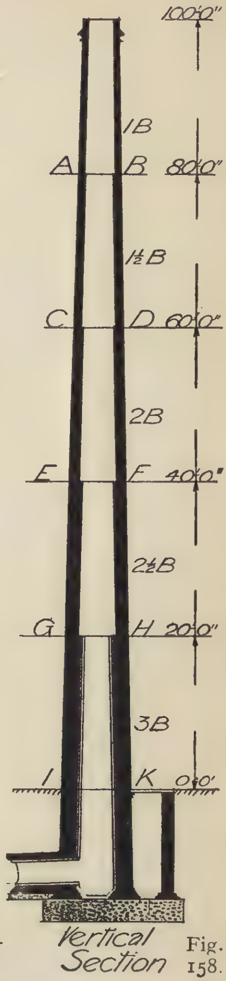


Fig. 158.

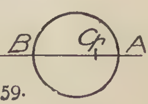


Fig. 159.

radial brick, which they apply for the building of tall chimneys, and thus take advantage of the increased adhesive value of the mortar.

Calculating by the first method, it is necessary to determine above the required section to be tested (1) the mass of the brickwork; (2) the moment of the mass about the centre of pressure; (3) the centre of wind pressure; (4) moment of wind pressure; (5) to equate the moment of the wind pressure with the moment of the mass. Determine safe wind pressure at bed joint AB, 20 feet from the top.

(1) Mass of brickwork above AB—

$$= \cdot 7854\ (D + d)\ (D - d) \times h \times w$$
$$= \cdot 7854\ (8 \cdot 83 \times 1 \cdot 5) \times 20 \times 112$$
$$23{,}302 = m_1$$

(2) Moment of mass—

$$= m_1 \times \frac{d}{4}$$
$$= 23{,}302 \times \frac{5 \cdot 583}{4}$$
$$32{,}523$$

(3) Centre of wind pressure $= y$. This may be obtained from the formula—

$$y = \frac{h}{3}\left(\frac{2A + B}{A + B}\right)$$
$$= \frac{20}{3}\left(\frac{2 \times 4 \cdot 75 + 5 \cdot 583}{4 \cdot 75 + 5 \cdot 583}\right)$$
$$= 9 \cdot 73 \text{ ft.}$$

(4) Moment of wind pressure—

$$= P \times \text{area pressed} \times \text{constant} \times \text{leverage}$$
$$= P \times \frac{4 \cdot 75 + 5 \cdot 583}{2} \times 20 \times \cdot 66 \times 9 \cdot 73$$
$$= 663 \cdot 5\ P$$

(5) Moment of wind pressure = moment of mass of wall—

$$663 \cdot 5\ P = 32523$$
$$P = \frac{32523}{663 \cdot 5}$$
$$= 49 \text{ lbs. nearly.}$$

Determine maximum allowable wind pressure at base C D—

(1) Mass of brickwork about C D, forty feet from the top—

$$= m_1 + m_2$$
$$= 23302 + \cdot7854\ (D + d)\ (D - d) \times h \times w$$
$$= 23302 + \cdot7854\ (9\cdot75 \times 2\cdot25) \times 20 \times 112$$
$$= 23302 + 38595$$
$$= 61897$$

(2) Moment of mass—

$$= \left(m_1 + m_2\right)\frac{d}{4}$$
$$= 61897 \times \frac{6\cdot416}{4}$$
$$99283$$

(3) Centre of wind pressure—

$$y = \frac{h}{3}\frac{2A + B}{A + B}$$
$$= \frac{40}{3} \times \frac{9\cdot5 + 6\cdot416}{4\cdot75 + 6\cdot416} = \frac{40}{3} \times \frac{15\cdot916}{11\cdot166} = 19 \text{ feet.}$$

(4) Moment of wind pressure—

$$= P \times \text{area pressed} \times \text{constant} \times \text{leverage}$$
$$P \times \frac{4\cdot75 + 6\cdot416}{2} \times 40 \times \cdot66 \times 19$$
$$2801\cdot2\ P$$

(5) Moment of wind pressure = moment of mass of wall—

$$2801\cdot2\ P = 99283$$
$$P = \frac{99283}{2801\cdot2}$$
$$P - 35\cdot44.$$

Determine safe maximum allowable wind pressure at base E F.

(1) Mass of brickwork upon E F, sixty feet from the top

$$= m_1 + m_2 + m_3$$
$$= 61897 + \cdot7854\ (D + d)\ (D - d)\ h \times w$$
$$+ \cdot7854\ (10\cdot66 \times 3)\ 20 \times 112$$
$$= 61897 + 56262$$
$$= 118159$$

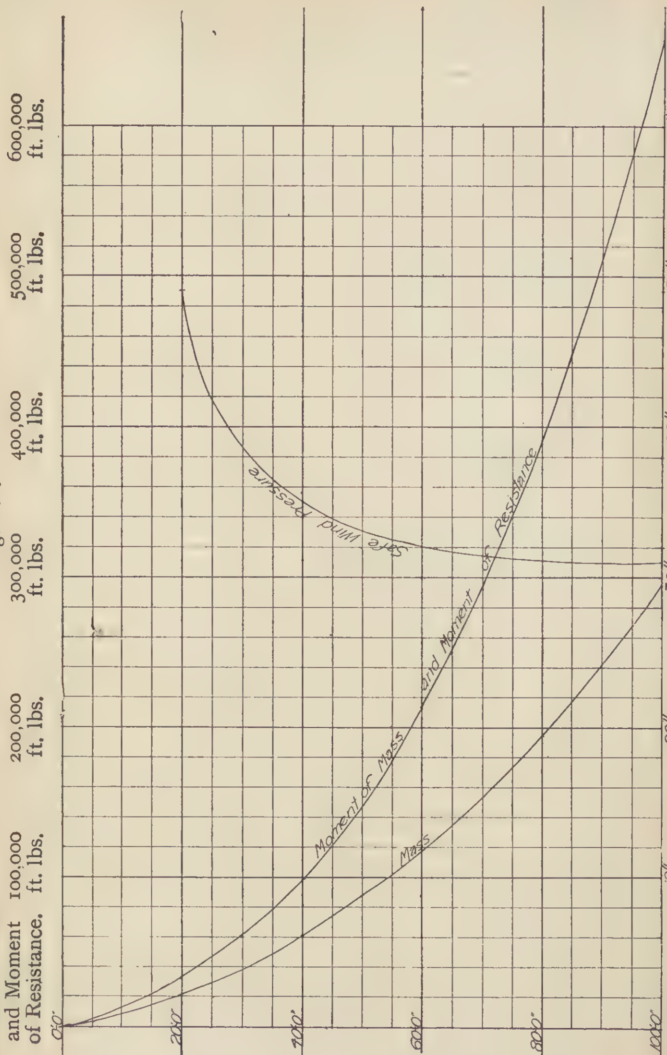


Fig. 160.

Scale for Safe Wind Pressures in lbs. per square foot, the height being measured from the top of the shaft.

(2) Moment of mass—

$$(m_1 + m_2 + m_3)\,\frac{d}{4}$$

$$118159\,\frac{7{\cdot}25}{4}$$

$$214163$$

(3) Centre of wind pressure—

$$y = \frac{h}{3}\left(\frac{2A + B}{A + B}\right)$$

$$= 20\left(\frac{9{\cdot}5 + 7{\cdot}25}{4{\cdot}75 + 7{\cdot}25}\right)$$

$$= 20 \times \frac{16{\cdot}75}{12} = 27{\cdot}917 \text{ feet}$$

(4) Moment of wind pressure—

$$= P \times \text{area pressed} \times \text{constant} \times \text{leverage}$$

$$P \times \frac{4{\cdot}75 + 7{\cdot}25}{2} \times 60 \times {\cdot}66 \times 27917$$

$$= 6633\ P$$

(5) Moment of wind pressure = moment of mass of wall—

$$6633\ P = 214163$$

$$P = \frac{214163}{6633}$$

$$P = 32{\cdot}313$$

Determine safe allowable wind pressure at base GH.

(1) Mass of brickwork upon GH, eighty feet from the top—

$$m_1 + m_2 + m_3 + m_4$$

$$118159 + {\cdot}7854\,(D + d)\,(D - d)\ 20 \times 112$$

$$+ {\cdot}7854\,(11{\cdot}583 \times 3{\cdot}75)\ 20 \times 112$$

$$= 118159 + 76418 -$$

$$= 194{,}577$$

(2) Moment of mass—

$$(m_1 + m_2 + m_3 + m_4)\,\frac{d}{4}$$

$$194577 \times \frac{8{\cdot}083}{4}$$

$$392300$$

(3) Centre of wind pressure—

$$y = \frac{h}{3}\left(\frac{2A + B}{A + B}\right)$$
$$= \frac{80}{3}\left(\frac{9{\cdot}5 + 8{\cdot}083}{4{\cdot}75 + 8{\cdot}083}\right)$$
$$= \frac{26{\cdot}66 \times 17{\cdot}583}{12{\cdot}833} = 36{\cdot}536$$

(4) Moment of wind pressure—

$$= P \times \text{area pressed} \times \text{constant} \times \text{leverage}$$
$$P \times \frac{8{\cdot}083 + 4{\cdot}75}{2}\, 80 \times {\cdot}66 \times 36536$$
$$12378\ P$$

Moment of wind pressure = moment of mass of shaft—

$$12378\ P = 392300$$
$$P = \frac{392300}{12378}$$
$$P = 31{\cdot}69$$

Determine safe allowable wind pressure on base I K.

(1) Mass of brickwork upon I K, one hundred feet from the top—

$$m_1 + m_2 + m_3 + m_4 + m_5$$
$$= 194577 + {\cdot}7854\ (D + d)\ (D - d)\ 20 \times 112$$
$$= \qquad + {\cdot}7854\ 13{\cdot}666 \times 4{\cdot}166)\ 20 \times 112$$
$$= 194577 + 100120$$
$$= 294697$$

(2) Moment of mass—

$$294697 \times \frac{d}{4}$$
$$294697 \times \frac{8{\cdot}916}{4}$$
$$656890$$

(3) Centre of wind pressure—

$$y = \frac{h}{3}\left(\frac{2\ A + B}{A + B}\right)$$
$$= \frac{100}{3}\left(\frac{9{\cdot}5 + 8{\cdot}916}{4{\cdot}75 + 8{\cdot}916}\right)$$
$$= \frac{100}{3}\left(\frac{18{\cdot}416}{13{\cdot}666}\right)$$
$$= 46{\cdot}038$$

(4) Moment of wind pressure—

$$P \times \text{area pressed} \times \text{constant} \times \text{leverage}$$
$$P \times \frac{13{\cdot}666}{2} \times 100 \times {\cdot}66 \times 46{\cdot}038$$
$$20762\ P$$

(5) Moment of wind pressure = moment of mass of wall—

$$20762\ P = 656890$$
$$P = \frac{656890}{20762}$$
$$= 31{\cdot}639$$

Figure 160 is a graphic representation of the moment of resistance in ft. lbs. of total pressure in lbs. over the whole area of the annulus at any section in the height, and the safe wind pressures in lbs. per square foot at any section.

Calculating by the second method, considering the shaft as shown in figures 156 to 158 as a series of cemented blocks.

Each section may be calculated, and the plane of weakest section may be found.

The wind pressure is assumed as 55 lbs. per square foot, and the problem is to determine the stress per unit area on the mortar joints in brick shafts or stress on the extreme fibres in reinforced concrete and steel shafts.

Determine stress fo at base AB, 20 feet from the top—

Moment of wind pressure = moment of resistance.

$$P \times \text{area pressed} \times \text{constant} \times \text{leverage} = \frac{fo\ I}{\delta}$$

$$fo = \frac{P \times \text{area pressed} \times \text{constant} \times \text{leverage} \times \delta}{I}$$

$$= \frac{\frac{55}{144} \times 5{\cdot}116 \times 12 \times 20 \times 12 \times {\cdot}66 \times 9{\cdot}73 \times 12\frac{67}{2}}{{\cdot}7854\ (33{\cdot}5^4 - 24{\cdot}5^4)}$$

$$fo = \frac{\text{anti-log } 7{\cdot}1622059}{706153}$$

$$fo = 20{\cdot}574\ \text{lbs.}$$

Pressure per unit area on base—

$$= \frac{\text{Weight of mass}}{\text{Area of base}} \left\{ \begin{array}{l} \text{Stress in compression} = \\ \qquad 20{\cdot}574 + 14{\cdot}208 = 34{\cdot}782 \text{ lbs.} \\ \text{Stress in tension} = \\ \qquad 20{\cdot}574 - 14{\cdot}208 = 6{\cdot}366 \text{ lbs.} \end{array} \right.$$

$$= \frac{23302}{{\cdot}7854\,(67^2 - 49^2)} \quad \left\{ \begin{array}{l} \text{Factor of safety in com-} \\ \text{pression in} \quad . \quad . \quad . \end{array} \right\} = \frac{34{\cdot}782}{400} = \frac{1}{11.5}$$

$$= \frac{23302}{1640} \quad \left\{ \begin{array}{l} \text{Factor of safety adhesion} \\ \text{of non-perforated bricks} \end{array} \right\} = \frac{6{\cdot}366}{21{\cdot}75} = \frac{1}{3{\cdot}4}$$

$$= 14{\cdot}208 \quad \left\{ \begin{array}{l} \text{Factor of safety adhesion} \\ \text{to perforated bricks} \quad . \end{array} \right\} = \frac{6{\cdot}366}{61{\cdot}5} = \frac{1}{9{\cdot}67}$$

Determine the stress on base C D 40 feet from the top—

Moment of wind pressure = moment of resistance.

$$\text{P} \times \text{area pressed} \times \text{constant} \times \text{leverage} = fo\,\frac{\text{I}}{\delta}$$

$$fo = \frac{\text{P} \times a \times c \times l \times \delta}{\text{I}}$$

$$= \frac{\frac{55}{144} \times 5{\cdot}7 \times 12 \times 40 \times 12 \times {\cdot}66 \times 19 \times 12 \times \frac{6{\cdot}416 \times 12}{2}}{{\cdot}7854\,(38{\cdot}5^4 - 25^4)}$$

$= 50{\cdot}15$ lbs.

Pressure per unit on base—

$$= \frac{\text{Weight of mass}}{\text{Area of base}} \left\{ \begin{array}{l} \text{Stress in compression} = 50{\cdot}15 + 22{\cdot}98 = 73{\cdot}13. \\ \text{Stress in tension} \quad\; = 50{\cdot}15 - 22{\cdot}98 = 27{\cdot}17. \end{array} \right.$$

$$= \frac{61897}{{\cdot}7854\,(77^2 - 50^2)} \quad \left\{ \begin{array}{l} \text{Factor of safety in com-} \\ \text{pression} \quad . \quad . \quad . \end{array} \right\} = \frac{73{\cdot}13}{400} = \frac{1}{5{\cdot}47}$$

$= 22\,98$ lbs.

$$\begin{array}{l} \text{Factor of safety adhesion} \\ \text{(blue lias) non-perforated} \end{array} \left\{ \frac{27{\cdot}17}{21{\cdot}75} \text{ would fail.} \right.$$

$$\begin{array}{l} \text{Factor of safety adhesion} \\ \text{(blue lias) perforated} \end{array} \left\{ \frac{27{\cdot}17}{61{\cdot}5} = \frac{1}{2{\cdot}26} \right.$$

Determine the stress on base E F 60 feet from the top.
Moment of wind pressure = moment of resistance—

$$\text{P} \times a \times c \times l = fo\,\frac{\text{I}}{\delta}$$

$$fo = \frac{\text{P} \times a \times c \times l \times \delta}{\text{I}}$$

$$= \frac{\frac{55}{144} \times 6 \times 12 \times 60 \times 12 \times {\cdot}66 \times 27{\cdot}917 \times 12 \times \frac{87}{2}}{{\cdot}7854\,(43{\cdot}5^4 - 25{\cdot}5^4)}$$

$= 76{\cdot}78$

Pressure per unit on base—

$$= \frac{\text{Weight of mass}}{\text{Area of Base}}$$

$$= \frac{118159}{\cdot 7854\,(87^2 - 51^2)}$$

$$= 30{\cdot}28 \text{ lbs.}$$

Stress in compression $= 76{\cdot}78 + 30{\cdot}28 = 107{\cdot}06$ lbs.

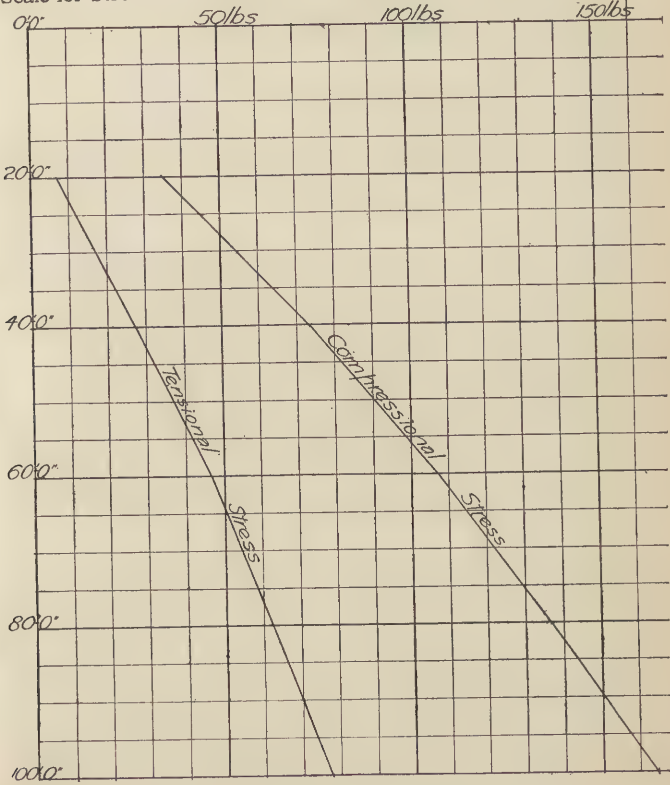
Stress in tension $= 76{\cdot}78 - 30{\cdot}28 = 46{\cdot}50$ lbs.

Factor of safety in compression . . . $= \frac{107{\cdot}06}{400} = \frac{1}{3{\cdot}7}$

Factor of safety blue lias adhesion non-perforated bricks . . $= \frac{46{\cdot}5}{21{\cdot}75}$ would fail.

Factor of safety blue lias adhesion perforated bricks . . . $= \frac{46{\cdot}5}{61{\cdot}5} = \frac{1}{1{\cdot}3}$

Scale for Stress in Tension and Compression per square inch.



From top of shaft.

Fig. 161.

Determine the stress on base G H 80 feet from the top—

$$fo = \frac{P \times a \times c \times l \times \delta}{I}$$

$$= \frac{\frac{55}{144} \times 6{\cdot}4165 \times 12 \times 80 \times 12 \times {\cdot}66 \times 36{\cdot}536 \times 12 \times \frac{97}{2}}{{\cdot}7854\ (48{\cdot}5^4 - 26^4)}$$

$= 99{\cdot}38$ lbs.

Pressure per unit on base—

$$= \frac{\text{weight of base}}{\text{area of base}}$$

$$= \frac{194577}{{\cdot}7854\ (97^2 - 52^2)} =$$

$$= \frac{194577}{{\cdot}7854\ (149 \times 45)}$$

$= 36{\cdot}86$ lbs.

Stress in compression $= 99{\cdot}38 + 36{\cdot}86 = 136{\cdot}24$ lbs.

" tension $= 99{\cdot}38 - 36{\cdot}86 = 62{\cdot}42$ lbs.

Factor of safety compression blue lias $= \frac{136{\cdot}24}{400} = \frac{1}{3}$

" " adhesion " " non-perforated brick $= \frac{62{\cdot}42}{21{\cdot}75}$ would fail

" " " " " perforated brick $= \frac{62{\cdot}42}{61{\cdot}5}$ would fail

" " " cement $\frac{62{\cdot}42}{280} = \frac{1}{4{\cdot}48}$

Determine the stress at base I K, 100 feet from the top, where the stresses on the extreme fibres are the greatest.

Moment of wind pressure = moment of resistance.

$$P \times \text{area pressed} \times \text{constant} \times \text{leverage} = \frac{fo\ I}{\delta}$$

$$\therefore fo = \frac{P \times \text{area pressed} \times \text{constant leverage} \times \delta}{I}$$

$$= \frac{\frac{55}{144} \times 6{\cdot}833 \times 12 \times 100 \times 12 \times {\cdot}66 \times 46{\cdot}038 \times 12 \times \frac{8{\cdot}916 \times 12}{2}}{{\cdot}7854\ (53{\cdot}5^4 - 26{\cdot}5^4)}$$

$$= \frac{733047796}{6047028}$$

$= 121{\cdot}23$

Pressure per unit area on base—

$= \dfrac{\text{weight of mass}}{\text{area of base}}$	Stress in compression $= 121{\cdot}23 + 43{\cdot}42 = 164{\cdot}65$ Stress in tension $= 121.23 - 43{\cdot}42 = 77{\cdot}81$	
$= \dfrac{294697}{{\cdot}7854\,(107^2 - 53^2)}$	Factor of safety in compression (blue lias) .	$\dfrac{164{\cdot}65}{400}$
$= \dfrac{294697}{6785{\cdot}9}$	Factor of safety adhesion (blue lias) non-perforated bricks .	$\dfrac{77{\cdot}81}{21{\cdot}75}$ would fail
$= 43{\cdot}428$	Factor of safety adhesion (blue lias) perforated bricks . .	$\dfrac{77{\cdot}81}{61{\cdot}5}$ would fail
	Factor of safety adhesion (Portland cement) non-perforated bricks	$\dfrac{77{\cdot}81}{280} = \dfrac{1}{3{\cdot}6}$

Figure 161 is a graphical representation of the tensional and compressional stresses in lbs. per square inch, on the bed joints throughout the height of the shaft, measured from the top.

Lightning Conductors.—Chimney shafts and the highest parts of structures elevated above surrounding objects should be protected from the effects of lightning by attaching a metal band of good conductivity to form an electrical connection between the earth and the clouds. All metals are good conductors, compared to the other materials of a structure, and will collect and convey currents, which, if not properly guided away from the building, are likely to form a source of danger to the structure. All metal parts, such as gutters, should be connected with the conductor. The lightning conductor is usually a band or rod of copper or iron commencing at the highest part of the structure, where it is connected to a terminal extending from 4 to 6 feet above the highest part. The end of the terminal is pointed, and has a number of pointed branches extending out from the central stem. The conductor is fixed to the wall, often close to it, and is continued down to the ground; here it is diverted horizontally so far away from the structure as is necessary to find good moist earth, and attached to a metal

plate, usually copper, about $\frac{1}{16}$ inch in thickness, and at least 3 feet square, the actual area depending upon the nature of the earth, which should be wet; the drier the ground, the larger therefore will be the required area. In order to obtain an efficient contact, the earth-plate is surrounded by powdered coke about 6 feet below the surface of the ground. Copper is a better conductor than iron in the ratio of 100 to 17, and the relative areas to convey a similar current would, therefore, be in the inverse ratio. Copper is easier to manipulate about the various architectural projections, but iron is better to resist fusion. Care should be taken that all joints are efficiently made, so that the pieces joined are in actual contact. Copper should be riveted and soldered, and the iron screwed or riveted according to section.

The zone protected by a conductor is generally considered to be that space enclosed by a cone, the base of which is twice its height, hence the necessity in long exposed buildings to have conductors at all salient points. Figure 150 shows the shaft protected by a lightning conductor attached, taken down to the ground and properly earthed.

It has recently been shown that the conductor must be not only a good conductor but as free from electric inertia as possible, avoiding all bends and smoothing down all changes of directions. On similar grounds the single rod is changed for a series of stout wires rising at all corners and making a fringe of points above the roof, the elevation of each point above the roof being very much less than in the case of a single rod. Advantage is taken of all external conductors by making them form a network with the wires provided.

Skew Arches.—These occur where a deep brick arch, such as a bridge, spans a road or waterway, and makes with the same any angle other than a right angle.

The abutments of such an arch are made parallel to the road, and the direction of the bed joints in the soffit, as in every other arch, must be at right angles to the pressure. Let the arch be semi-cylindrical, then the bed joints between the courses will take the form of a number of helical surfaces, which wind about the cylinder, and the beds as seen on the soffit will not be the same height in any two parts; if the arch be of stone, considerable skill is required in cutting the voussoirs, as the bed joints of each will be on the twist; the side joints of the voussoirs will also form a number of helical surfaces parallel to the face of the arch, and at right angles to the bed joint helices. These in rough brick arches are not studied, as the blocks are so small; great care, however must be taken in starting the springers. The ends of the bricks that intersect the face of the arch often require to be cut at a very acute angle. This, in brickwork, is bad, such angles being weak. They are, therefore, where the appearance is of no great importance, left square.

The method of setting out these arches for masonry, the lines for which are similar, is shown in the chapter on Masonry.

Brick Drains.—These are large conduits for sewage, rain and waste water; and are employed where the sectional area required is greater than can be obtained by using stoneware pipes, *i.e.*, about 2 feet diameter. They are made of various sections, the two most generally used being the circular and the egg-shaped.

Circular Drains are usually constructed of at least two half-brick rings set in cement; on a concrete foundation formed round a centre, on the concrete bed the invert of the arch is laid, the upper part of the drain being built in the usual way as an arch with a centre support.

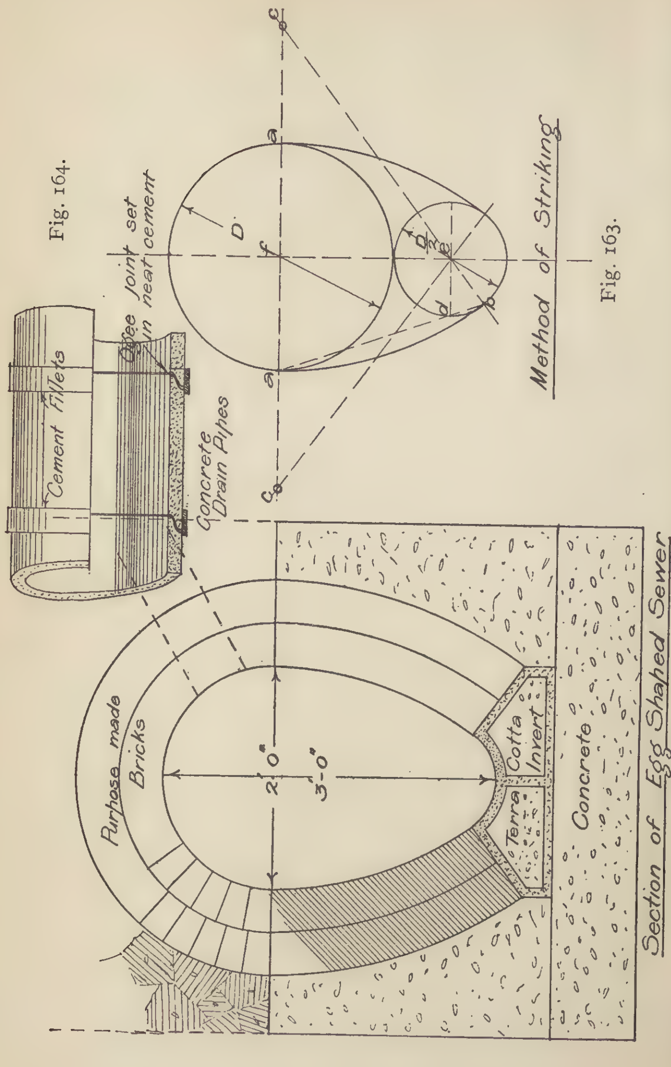


Fig. 164.

Fig. 163.

Fig. 162.

Concrete drains, as shown in figure 164, are made by Messrs. Sharp, Jones & Co., of Dorsetshire. They are efficient and economical, and are now largely used from 15 inches diameter and upwards as surface and foul water drains. The concrete sections are laid and then jointed with neat cement.

Reinforced Concrete Drains.—Drains, sewers, and water conduits are now being largely made in ferro-concrete. They may be moulded in situ, forming monolithic blocks, or made in sections and jointed. Where great pressures are anticipated the former method is employed. The reinforcements consist of longitudinal bars laced to circular or other shapes, and forming a network of steel.

Egg-shaped Sewers.—These, as shown in figure 162, are employed to increase the velocity of the flow by making the current deeper; the advantage of this shape over the circular one is most apparent when there is only a small quantity of water in the drain. The method of striking the curves is shown in figure 163. The construction is as follows:—a bed of concrete, with a horizontal surface levelled to the proper falls, is laid in the trench; on this the invert is bedded, this being made of blue Staffordshire bricks or vitrified stoneware of the shape shown. Concrete is then shot in behind a centre to the height of the invert; the bricks to the latter point are now laid generally in two half-brick rings, the upper part is then completed on a centre, and the earth filled in. Any connections that are made to the sewer from the house drains should be taken through the sides just beneath the spring of the covering arch, which is the highest point to which water would rise under ordinary conditions. All house drains should have an iron flap trap on the outlet end to prevent any back flow, should the sewer become filled or the water line rise above the normal, as it often does after heavy

Fig. 166.

Fig. 165.

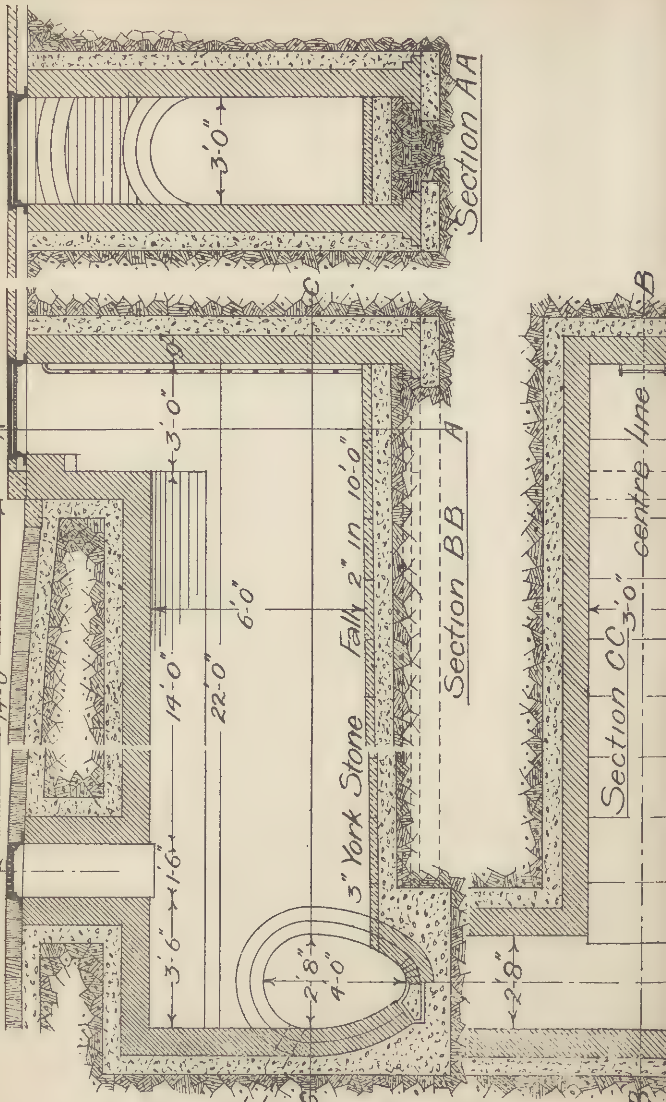


Fig. 167.

rains; these flap traps also help to prevent any vermin entering the house drains from the sewer. Sewers are usually built of ordinary shaped bricks, which leave a large wedge-shaped joint; to avoid this defect specially shaped bricks are now largely employed.

The outline for oval or egg-shaped sewers, as shown in figure 163, may be described as follows:—let two-thirds of the required depth be taken as D, the diameter of the circle *f*; to describe another circle about centre *e*, with diameter $\frac{D}{2}$ tangent to D, join by a straight line centres *f* and *e*, and draw perpendiculars to this line passing through *f* and *e*, and produce these lines intersecting circles in *a* and *d*; join *a* and *d* by a straight line, and produce till it cuts circle *e* at *b*; join *b* and *e* by a straight line and produce till it cuts *a f* produced in *c*; then, because the triangles *e d b* and *c a b* are similar, *c* is the centre of a circle tangent to circles *f* and *e* at the points *a* and *b* respectively.

Figures 165 to 167 show three views illustrating sections of sewer, side inlet, manhole, and ventilating shaft in the centre of the roadway.

CHAPTER IV.

MASONRY.

(Continued from the Author's Elementary Course.)

VAULTING.

Classification.—Chambers covered with brick, stone, or concrete are termed vaults and may be classified under three heads:—

1. Barrel Vaults. 2. Domes. 3. Rib and Panel Vaults.

Barrel Vaults.—A barrel vault consists of a continuous arch, resting upon the side walls of a building, which must be very thick in order to resist the thrust of the vault which is distributed along the whole length of the vault; the walls thus become in effect continuous buttresses. Where barrel vaults intersect each other the line of intersection is known as a groin. To exactly comply with the statical conditions, every part of the groin should lie in the vertical plane; for æsthetic reasons also this condition should apply. Such a straight groin can only be obtained when the radii of the intersecting vaults are equal and their springings are at the same level. In all other cases of intersecting vaults twisted groins will result, as shown in figures 168 to 171; all such intersections in barrel vaults are sources of weakness, which latter is very apparent. Figure 171 shows an interior with a barrel vault lit by means of a clerestory formed by smaller barrel vaults intersecting larger. The effect of this,

especially where the secondary vaults are large, is to concentrate the pressure of the vaults upon sections of the walls. This is a desirable result, as it enables thinner walls

Fig. 168.

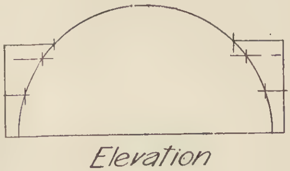
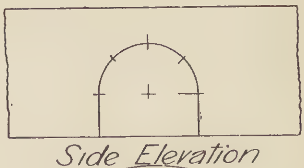


Fig. 169.



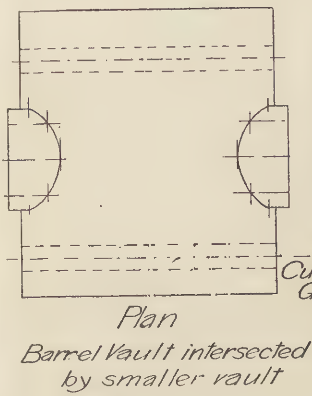


Fig. 170.

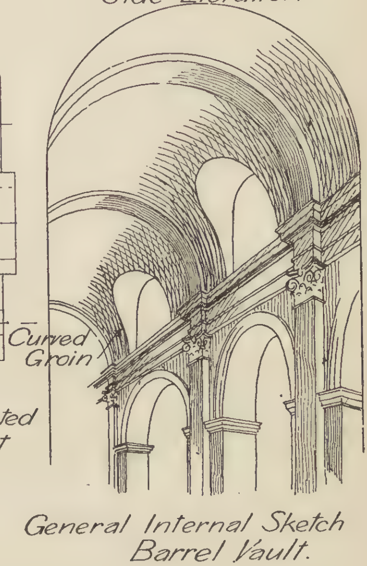


Fig. 171.

to be built, the points of concentration only requiring to be fortified by means of cross walls or buttresses.

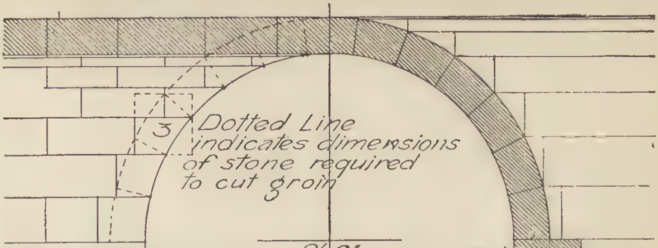
Figures 172 to 177 show the plan, sectional elevation and details for the construction of two intersecting barrel vaults of equal radii. Figure 173 shows the half plan and intersection of vault looking up. Fig. 175 shows the half

plan of the extrados looking down. Figure 172 is the half-sectional elevation showing intrados and groin. Figure 174 is a sectional elevation of the vault. Figure 176 shows the block of stone out of which No. 3 groin is to be worked, also the templet required. All other groin stones would be projected and worked similarly. Figure 177 is a perspective view of No. 3 groin when finished.

Domes.—A dome is a roof of the form of a semi-spheroid, ellipsoid, or conoid. In its simplest form it is constructed on a wall circular in plan. The dome is more often supported upon walls square or octagonal in plan, but any other regular polygon would apply equally well. If any polygon is inscribed in the great circle of a sphere and planes perpendicular to the surface of the polygon be projected through its sides, these will intersect the sphere in a number of circular sections. If these circular sections form portions of barrel vaults, the usual arrangement, as shown in figures 178 and 179, is obtained.

Types of Domes.—There are three distinct methods of arranging the dome:—1. Where the spheroid is intersected by four square walls, as shown in figures 178 to 180. In this case the dome appears very flat, a comparatively small portion only projecting above the line of intersection of intercepting walls. 2. In order to obtain greater internal height than in the preceding example let the upper part of the dome above the intersecting walls be considered to be cut off by a horizontal plane resting upon the highest points in the lines of intersection of the walls and dome. This will give a horizontal circle, and upon this a dome of smaller radius than the preceding dome can be constructed, as shown in figures 181 and 182. The portions of the large lower dome remaining between the four vertical walls and the horizontal plane are known as pendentives, as shown in figure 183; these practically form projecting corbels

Fig. 172. Fig. 174.



Half Sectional Elevation showing Groin.

Half Sectional Elevation through Barrel Vault.

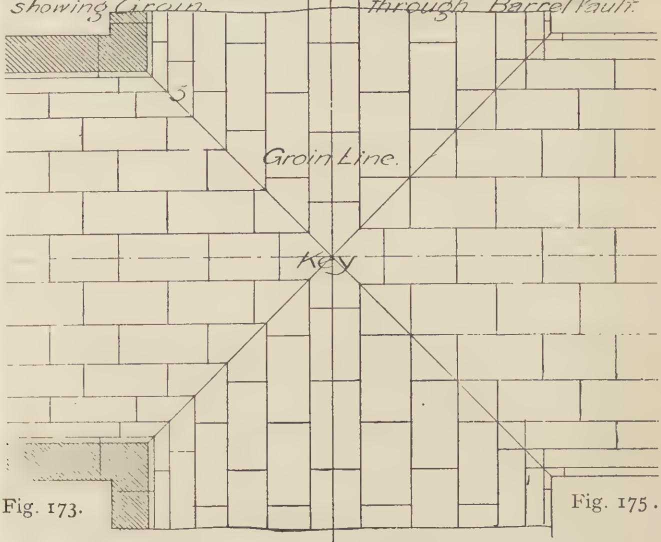


Fig. 173. Fig. 175.

Half Plan of Soffit.

Half Plan of Extrados.

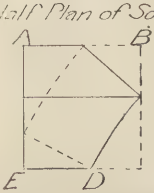
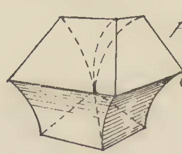


Fig. 176.

Outline of Templet for Nº 3 Groin.



Perspective view of Nº3. Groin Stone.

Fig. 177.

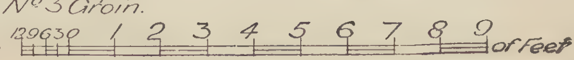
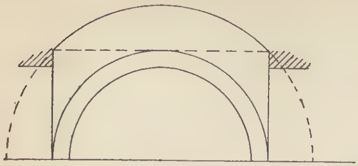
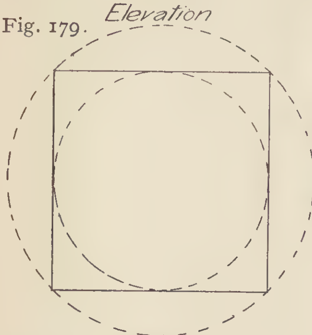


Fig. 178.



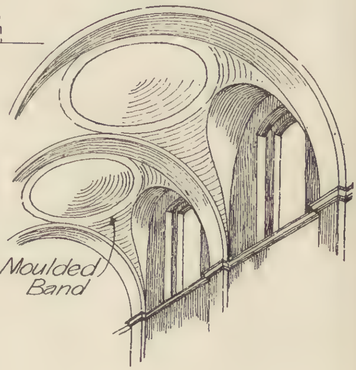
Elevation

Fig. 179.



Plan.

Fig. 180.



General Sketch

Fig. 181.

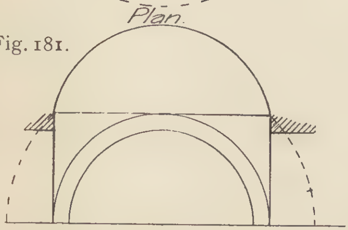


Fig. 182. *Elevation*

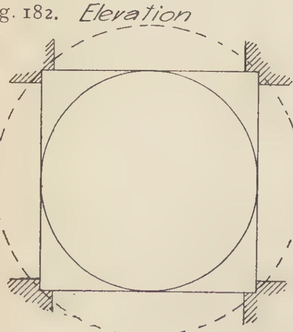
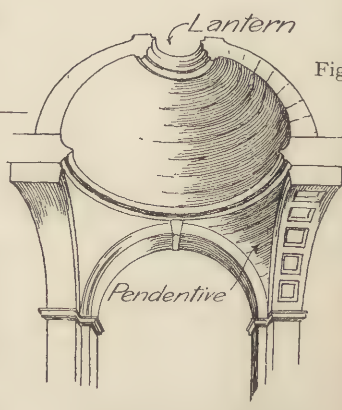


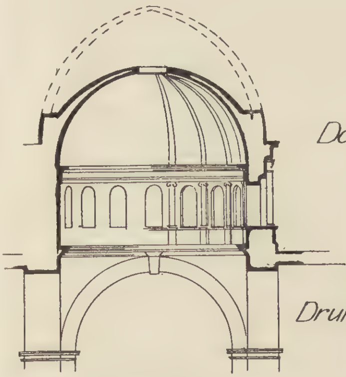
Fig. 183.



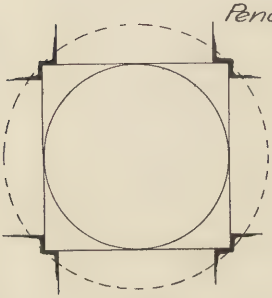
General Sketch.
Pendentive Dome.

constructed so that the square or other polygon may be developed into a circle upon which the smaller or true dome may be supported.

Fig. 184.

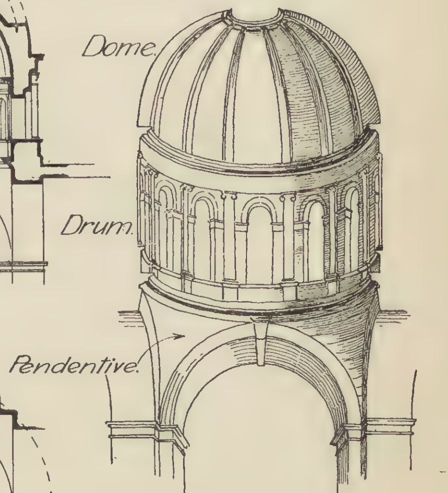


Elevation.



Plan

Fig. 185.



General Internal Sketch Pendentive Dome with Drum

Fig. 186.

In the third case, as shown in figures 184 to 186, in order to obtain still greater internal height the smaller dome is elevated upon a circular wall, known as the drum, which rests upon the horizontal circle to which attention has been drawn in the preceding example.

General Description.—Domes are usually constructed of stone or concrete; where of stone they are built in horizontal courses, each of which forms a horizontal arch. Supposing means to be taken to prevent these rings from spreading or opening, then each ring when complete is maintained in equilibrium by the side thrusts of its several voussoirs and the support it receives from the ring immediately below it. Thus in constructing such a dome no centre is required, only temporary supports until the ring being built is complete; owing to this the central portion may be omitted for purposes of lighting, for which lanterns are usually provided. The lower or upper surfaces of the bed joints of each ring if produced would form a cone. There is a tendency for the dome to spread at a point somewhere between the haunch and the base. In the first method the dome is usually sunk well within the walls and there is no fear of spreading; in the second example the wall may be carried up and constructed of a thickness and weight sufficient to resist its outward thrusts, but in the third case this cannot easily be done without a great expenditure of material and the effacement of the dome as an external feature. To prevent spreading in this case a metal band, encircling the dome at some line between the base and the haunch, is employed to tie the structure together. In many of the large types of domical structures, two domes are employed, an internal and an external dome; this is done to gain effect from both the interior and the exterior. A very tall dome internally presents a cavernous effect and cannot be properly viewed from the inside. A low dome such as would present a good appearance internally would from the exterior appear stunted.

Domes are frequently now constructed of concrete, which has become possible from an economical point of view since the introduction of such a powerful matrix as Portland cement. They are constructed upon a wood centre, upon which the concrete is deposited in regular horizontal

Fig. 196.

Fig. 195.

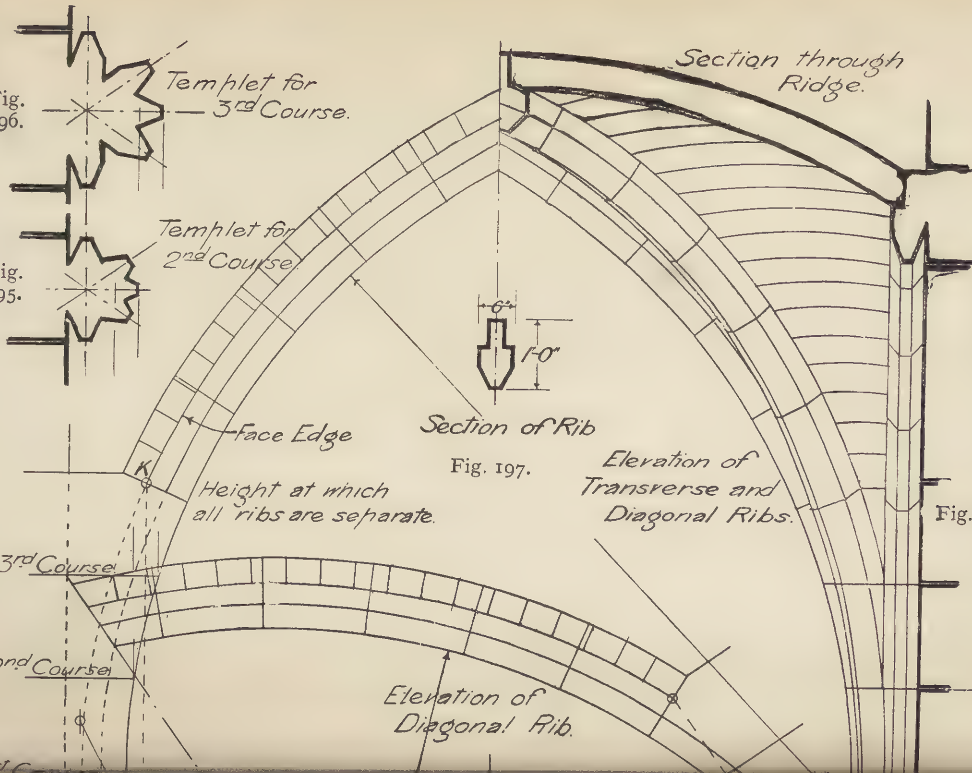
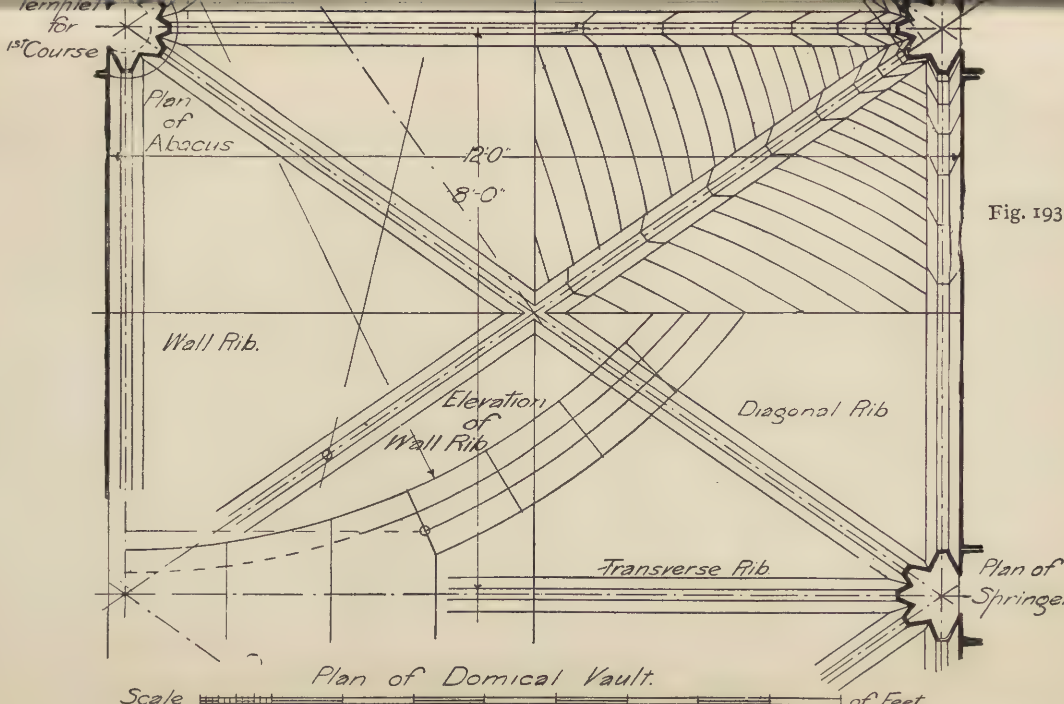


Fig. 197.

Fig. 194.

Fig. 193.



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rings. If iron ribs be inserted in the concrete, there is a tendency for fractures to occur following the lines of the ironwork. If iron or steel is used it should be in small circular sections interlaced throughout as described in the article on ferro-concrete.

Rib and Panel Vaults.—In the reference to the barrel vaults it was pointed out that the groin was a line of weakness, and where bent was an apparent defect ; to remedy which efforts were made to construct vaults of varying radii whose line of intersection should be in a vertical plane. If two great semi-circles of a sphere, intersecting at their crowning points, and their extremities are distant from each other an amount equal to the spans of the vaults to be intersected, then let these extremities in plan be joined by lines and upon these latter erect semi-circles. If these semi-circular surfaces be imagined to be moved upward, as shown in figure 187, along the great semi-circles, always keeping them in a vertical position, curved surfaces will be generated that will intersect in the great semi-circles as shown in figure 187. If these great semi-circles are constructed as two intersecting stone arches they will emphasize the groin, and will form support for the vaulted surfaces. A form of vault or arch that will exert a less horizontal thrust upon the walls or supports is the pointed arch or vault. This form of vault was at first used as a barrel vault, and at a later date for the rib and panel vaults, for the purpose of reducing the horizontal thrust. Figure 188 shows the form of a pointed groined vault. This and the preceding example are known as domical vaults.

Figures 193 to 197 show the working drawings for a domical vault. The ribs of this vault, as shown in Figures 193 and 194, all form segments of similar curves. As all the ribs are of varying spans and segments of similar circles the apex of each system will occur at different heights,

Fig. 187.

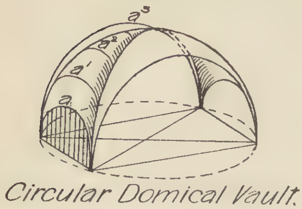
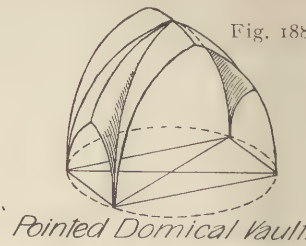


Fig. 188.



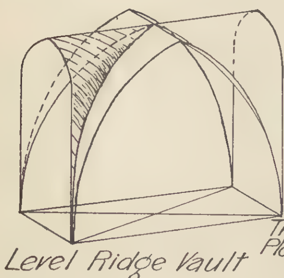


Fig. 189.

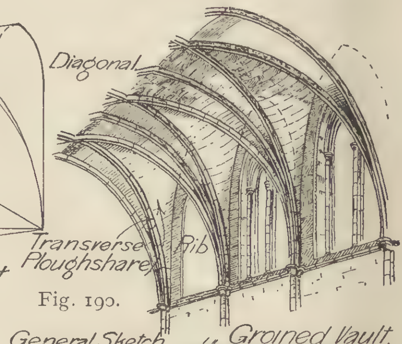


Fig. 190.

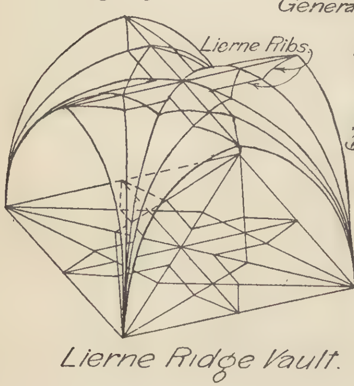


Fig. 191.

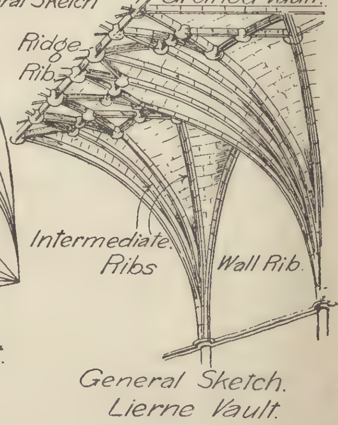


Fig. 192.

and as the panelling is all built concave on the under surface the ridge lines joining the apices will be curved also.

In order that the panels may rest upon the ribs uniformly at all points, it is necessary that the face edges as shown in Figure 194 of adjacent ribs shall separate at the same height. It will be noted that in an oblong vault, as shown in Figure 193, the diagonal and transverse ribs intersect at a higher level than the diagonal and wall ribs, but the highest point at which all the ribs separate is taken, and all the ribs constructed as portions of similar arcs up to that point; by so doing all the mouldings and face edges will intersect uniformly. To obtain this height draw the ribs in plan, from the point where the sides intersect erect a projector to cut the face edge in elevation, this will be the required height. At this height, K, the skewbacks in all cases are formed, and if the ribs are of varying curves, the curves commence to differ at this point; up to this height in which all the ribs are combined, the bed joints are made horizontal. Figure 197 shows the section of the rib employed, this would be cut out of zinc and used as the templet for cutting the arch rib stones; for obtaining the templets for cutting the corbel courses (Figures 195 and 196), project from the elevation on to the plan of the transverse ribs, Figures 195 and 196, the increased lengths of the members due to these joints not being normals to the curves. As all the ribs are portions of similar segments, these lines may be swung round from the centre, O, till they cut the centre line of each rib, and thus the projections of each member may be drawn.

The Panelled Surface.—The exact form of the panelled surface is immaterial provided the under surface is concave, the direction of the bed joints may be parallel to the ridge line, as was the common method employed in France; in

England it was usual to place the bed joints at some angle to the ribs on which they rested, generally about right angles to the line bisecting the lower angle of the panel; it is important whichever way the courses are laid that they should be concave on their under surfaces, so that each course when complete will form an arch and will only require supporting until that particular course is built, and thus the whole surface will not require a special centre for its construction as would be required for a barrel vault.

Level Ridge Vaulting.—This principle understood, general efforts were made to raise the crowns of the intersecting vaults to the same level, until finally the ridge lines were level. In the pointed vaults, no matter what the span, the crown can always be raised to any level required by lengthening the radius; but this, where the intersecting vaults vary much in their span, would give an unsightly lancet shaped slit for the narrow vault. To remedy this the springing of the narrow vault was raised to the height required, thus causing the panelled surface to lie for a portion of its length in the vertical plane, and giving a twisted surface to the panel, termed a ploughshare from its resemblance to that instrument.

Figures 189 and 190 show a diagram and sketch of a level ridge vault. Figures 198 to 200 show the working drawings for a level ridge vault. Figure 198 shows the plan of one bay with the elevation of the diagonal and wall ribs. Figure 199 shows the elevation of the transverse rib and a half-sectional elevation taken through the ridge of the vault and the position of the ploughshare panel, the diagonal and transverse ribs are struck to the same curve up to the height of the point K, at which point they commence to have a separate existence and from which the arch proper commences; it may be noted that the springing of the wall rib has been raised, the result of which is to

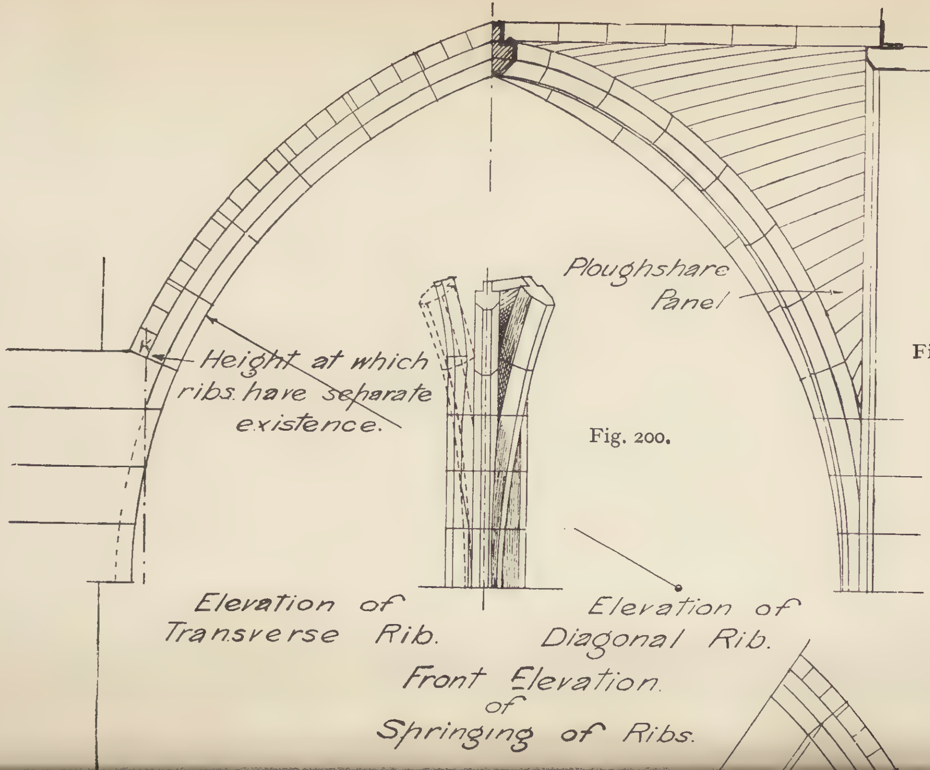
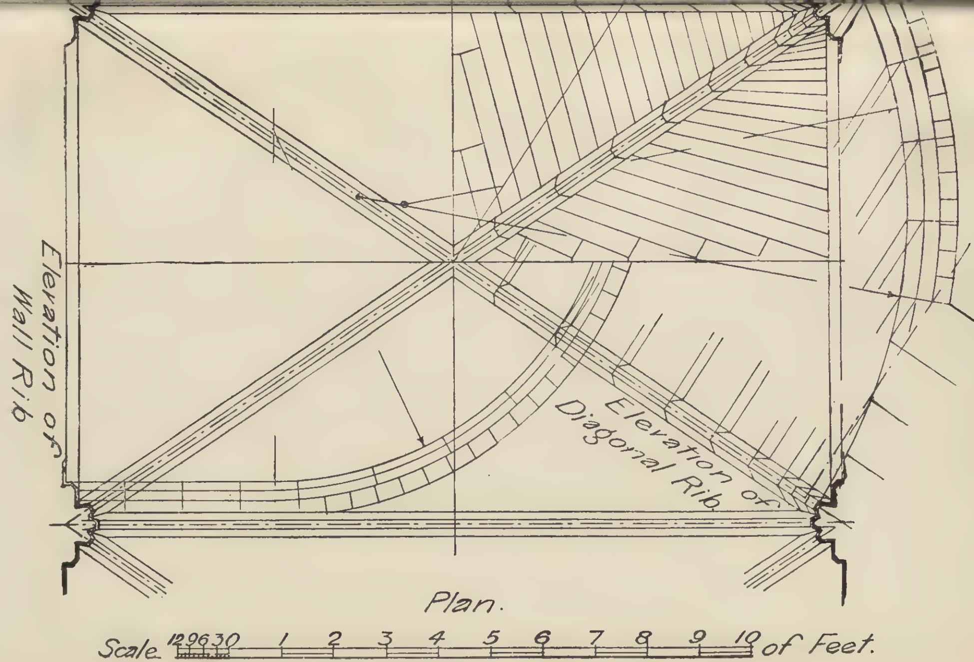


Fig. 199.

Fig. 200.



Level Ridge Vaulting.

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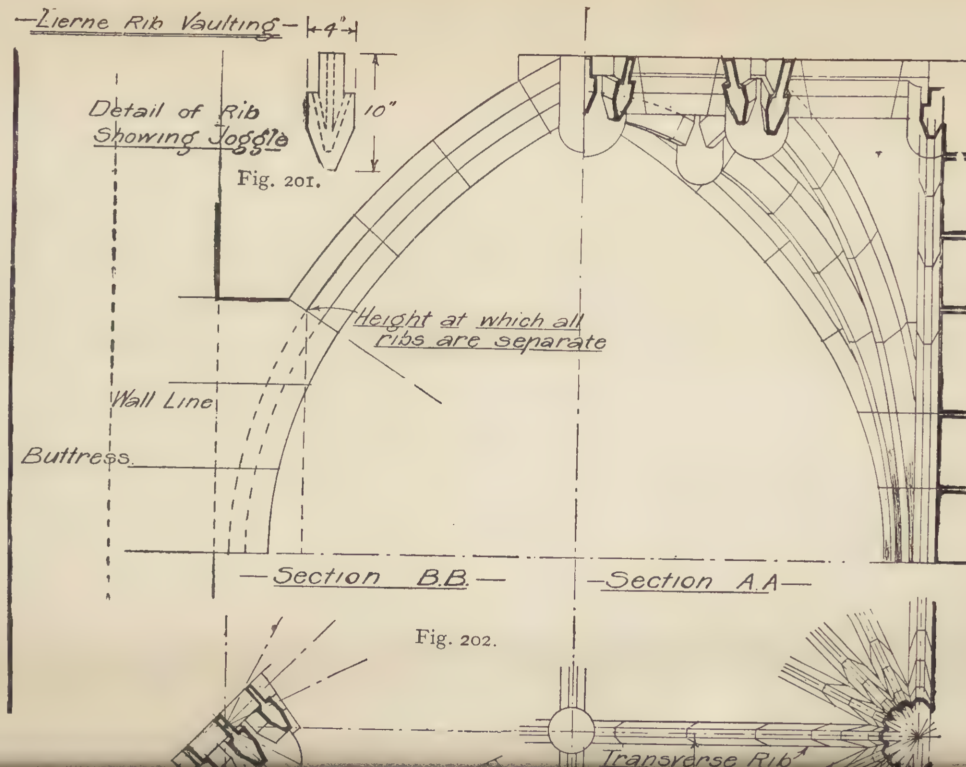


Fig. 201.

Fig. 202.

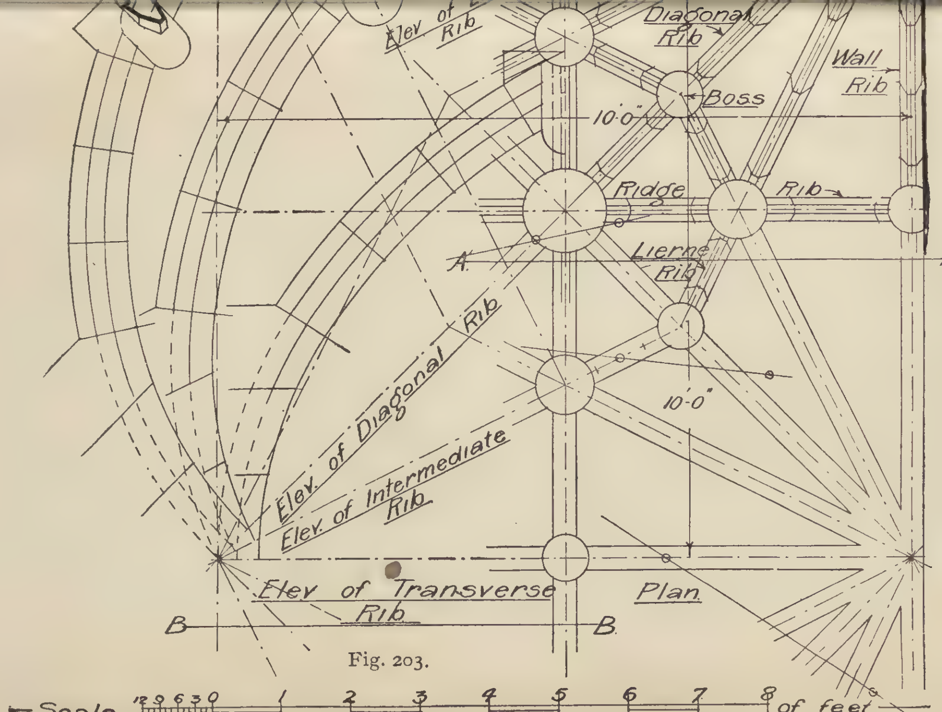


Fig. 203.

[Between pages 302 and 303.

form a ploughshare panel. Figure 200 shows the front elevation of the ribs at the springing. Figure 198 shows the method of projecting the joint lines in plan from the elevation of the rib.

The direction of the courses of the filling in or panelling must make an angle with the ridge. The courses are generally arranged at right angles to the line which bisects the lower angle of the panel.

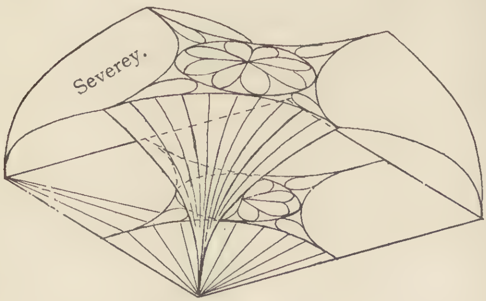
The reason governing and satisfied by this method of procedure is that it is required that each course when laid shall form an arch in itself. If this be done no centres are required for the panelling, but only temporary supports for each course till they are completed.

Lierne Rib Vaulting.—In the later developments of the rib and panel vaulting there was a tendency to cover large spans; this necessitated the introduction of intermediate ribs between the diagonal and the wall or transverse ribs to strengthen the panelled surfaces. This rendered it imperative to employ ribs at the ridge also. The next stage was to stiffen the groin ribs by means of shorter ribs placed between them; these were arranged to some geometrical pattern, generally a star-shaped figure, and were termed "lierne ribs" from the French word "lier," to bind. To facilitate the setting out and to simplify the construction, the centre plane of these ribs were kept vertical; this rendered it impossible to properly intersect the mouldings at the junction of the ribs, but this difficulty was surmounted by substituting for the intersection a boss of stone, generally carved. Figures 191 and 192 are diagrams showing lierne ribs and a general sketch.

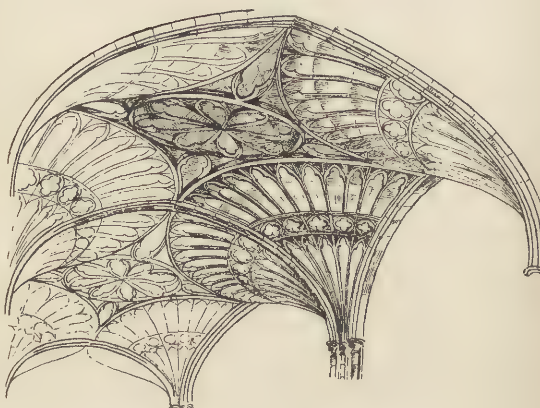
Figures 201 to 203 show the working drawings of a lierne rib vault. Figure 203 gives the plan of the vaulting as seen from below, also elevations and true shapes of the transverse, intermediate, diagonal and lierne ribs. It may

be noted that the boss stones at the points of intersection are formed level on their upper surfaces, on this the angles and widths of the projecting arms can be accurately set

Fig. 204.



Fan Vault.



General Sketch Fan Vault.
Fig. 205.

out. The bevils for all the bed joints for the boss stones can also be obtained from these projections. Figure 202 shows two sections, one at B B showing the section through

the transverse rib, wall, and buttress; the other, through A A, showing the elevation of the vault. Figure 201 shows a section of the rib employed, with the position of the cement joggle.

Fan Vaulting.—The tendency of the development of the rib and panel vaults was to increase the number of the intermediate ribs, at the same time to make them lighter, which led up to constructing every rib as a portion of similar curves springing from the same point, and the ribs having an equal angular distance between them which culminated in the severeys becoming portions of inverted conoids. The intersection of the conoids gave an undulating line along which a ridge rib was usually formed. The number of ribs was increased to such an extent that in the fully-developed style they ceased to exist as separate members but became merely projections formed by the sinking of the panels. Horizontal ribs, as shown in figure 205, were formed at intervals in the height of the conoid for decorative purposes and to afford an opportunity of increasing the number of ribs as they approached the ridge. In some instances the ridge ribs were continued through from end to end of the chamber; in others the quadrilateral surface in the centre of the compartment left between the intersecting horizontal ribs was filled in by circular panels or other traceried designs having no reference to the ribs of the conoid, as shown in figures 204 and 205. The chamber was frequently divided into compartments by transverse arches and each compartment roofed by four inverted quarter conoids.

Bridge Construction.—Bridges constructed of brickwork or masonry are built in the following manner: the span of arch or arches and their rise and radius are determined upon; from these the depth of the arch may be obtained by employing

Rankine's formula given in the chapter on Graphic Statics. Next the external spandril walls with the footpath and roadway are designed; the latter is supported by internal spandril walls, these being arched over or covered by slabs of stone to form a platform upon which the road can be built. The spandril walls where high are stiffened by means of cross or tie walls at intervals, as shown in figures 211 to 213.

Let it be required to construct a bridge of 50 feet span and with a rise of 21 feet, the arch and external spandril walls to be of granite, the internal spandril and tie walls of brick, the spandril walls to be connected by brick arches, upon which a bed of concrete is laid to form a foundation for the road consisting of granite sets and the footpath of 2-inch York paving.

	Weight of materials per cubic foot in lbs.
Granite	170
York Stone	165
Brickwork in Cement	115
Concrete (1 to 6)	140

Let the moving or live load on bridge be computed as 1 ton 19 cwts. per foot run of bridge, which should be doubled to obtain its equivalent dead load, viz.:

3 tons 18 cwts. per foot run of bridge.

Using Rankine's formula, the depth of the arch equals $\sqrt{\cdot 12 \text{ radius in ft. at crown}} = \sqrt{\cdot 12 \times 25} = 1{\cdot}732$, that is, 1 foot 9 inches, nearly.

The dimensions of all parts of the bridge are given in the figures 210 to 213.

To determine the stability of the arch let the bed joint of the first voussoir, which unsupported from above would overturn, be considered as the commencement of the arch proper, the lower voussoirs between this point and the springing being considered as corbels. Let the remaining

portion of the arch on one side of the centre line be divided into six equal sections, then the weights in tons of these sections with the road, load and balustrade computed will be as in the following table.

	1	2	3	4	5	6
Road, load, and balustrade ...	46·768	46·768	46·768	46·768	46·768	46·768
Spandril ...	·165	1·765	4·965	10·261	17·874	29·459
Arch	19·484	20·364	21·248	23·457	27·444	28·097
Total ...	66·417	68·897	72·981	80·486	92·086	104·324

Let the vertical lines passing through the centres of gravity of each of these sections be drawn as shown in figure 206, then by the method shown in the chapter on Graphic Statics determine the pathway of the resultant force, and the line of least resistance under the given distribution of the load, as shown in figure 206.

Let the arch now be tested for stability by satisfying the conditions of stability for uncemented blocks already given in the chapter on brickwork, and illustrated in the case of the stability of the arch in the chapter on Graphic Statics. If it is found that the proposed distribution of the load causes the line of resistance to fall without the prescribed limits, viz., without the middle third of the arch ring, as shown in figure 206, the load will have to be readjusted or added to, so that a line of resistance may be obtained that will fall within the middle third.

It will be found by inspection of the diagram, figure 206, that the line of least resistance falls outside the limits and approaches the intrados of the arch; the arch would therefore tend to open at the extrados at the haunches. Referring to the diagram, figure 207, the line of resistance has been raised to the least amount so that every part of it falls within the middle third. Now construct a new force polygon, the force

Q—a being the only force having the same value as in the first force polygon, by means of lines drawn parallel to the modified polar polygon or line of resistance. Parallels to lines of resistance on space Q and a, drawn from Q and a on force polygon will intersect in pole f, then from this pole draw parallels to sides of polar polygon on spaces b, c, d, e, P, these parallels will intersect Q—a produced in points b, c, d, e, P. This will give the required force polygon, from which may be measured the adjusted loads and the amounts to be added at each section. The following table shows the weight to be added, which may be in the form of concrete :—

	1	2	3	4	5	6
Required load	66·417	69·155	73·756	82·036	97·769	120·599
Total brought forward ...	66·417	68·897	72·981	80·486	92·086	104·324
Weight to be added (in concrete)...	—	0·258	0·775	1·550	5·683	16·275

Figures 206 to 213 show working drawings for the construction of the bridge. The bridge may be finished at the banks in one of two ways. If the hollow to be bridged over has high banks, as shown by dotted lines on the left hand side of figure 213, it would be constructed as shown in section ; but if the roadway to be supported by the bridge is elevated by an embankment above a level plane, abutments would be required sufficiently thick to resist the thrust of the arch, and the slopes of the embankment would be supported by retaining wing walls as shown in the figure 213.

Let a retaining wall be built of granite, 170 lbs. per foot cube, to hold back a mass of clay 120 lbs. per foot cube, the angle of repose of which is 45°, the section of retaining wall to be 6 feet at the base, and at the top 2 feet in

Fig. 206.

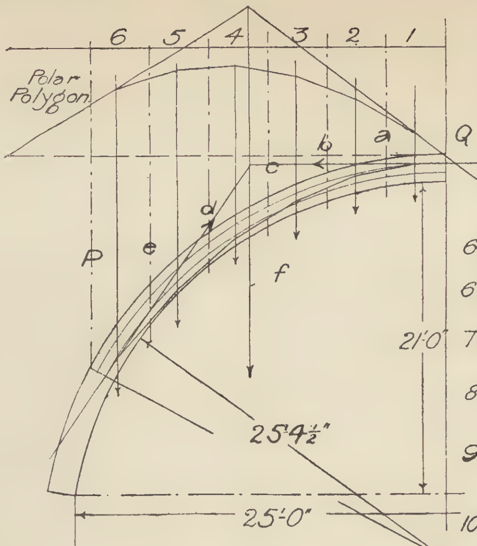
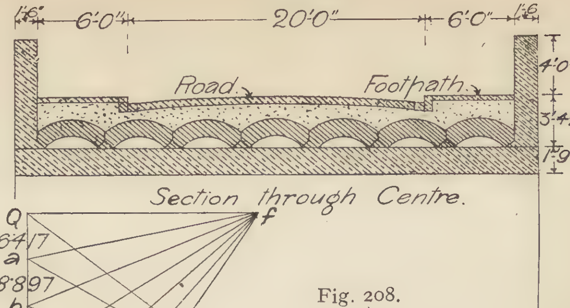


Fig. 210.



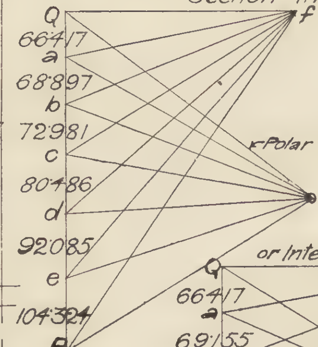


Fig. 208.

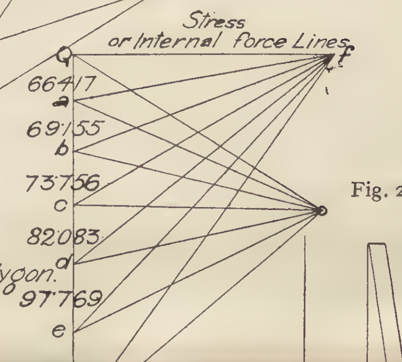


Fig. 209.

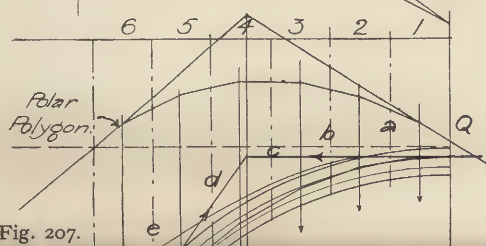


Fig. 207.

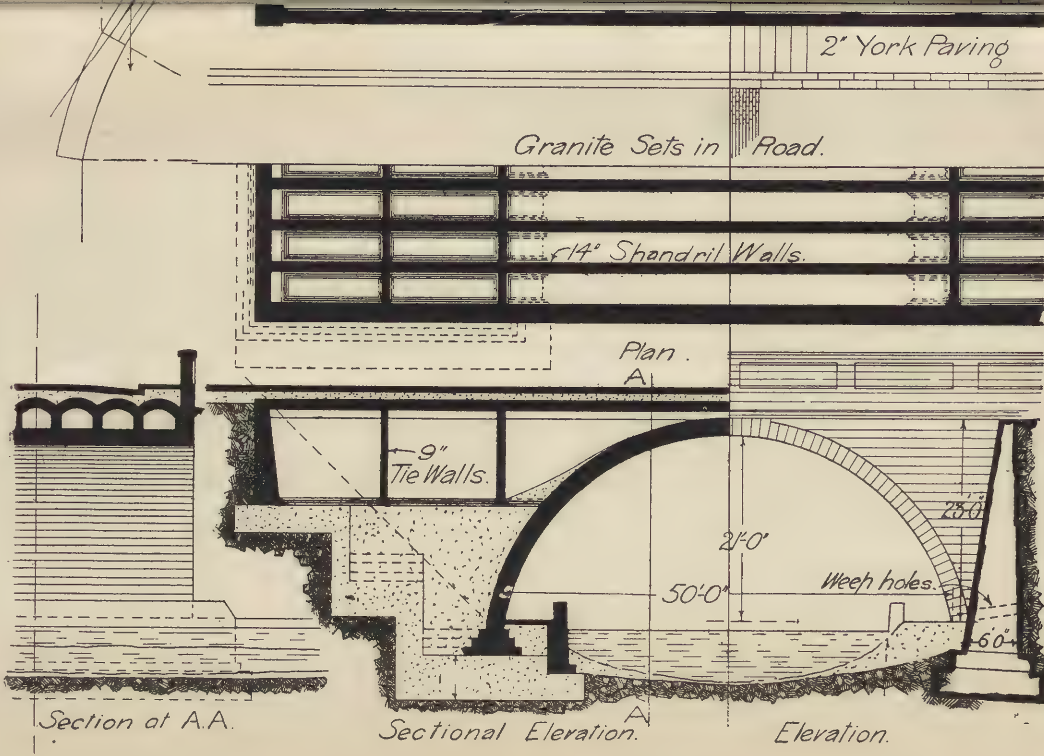


Fig. 212.

Fig. 211.

Fig. 213.

[*Between pages* 308 *and* 309.

thickness, with a back approximately vertical. Determine the stability. From what has already been stated

$$\text{Moment of retaining mass} = \text{moment of sliding mass of earth}$$

$$h \times \text{average } t \times l \times w \times \text{leverage} = \left(h \times \frac{9\frac{1}{2}}{2} \times l \times w\right) \tan 22\tfrac{1}{2}^\circ \times \text{leverage}$$

$$h \times \frac{2+6}{2} \times 1 \times 170 \times x = \left(23 \times \frac{19}{4} \times l \times 120\right) 0{\cdot}4142136 \times \frac{h}{3}$$

$$h \times 4 \times 170 \times x = 5430 \times \frac{h}{3}$$

$$680 \times x = 1810$$

$$x = 2{\cdot}66 \text{ ft.} = 2 \text{ ft. } 8 \text{ in. nearly.}$$

The pathway of the vertical through centre of gravity of retaining wall is 3 feet 10 inches from its front face at the base, therefore the resultant of the mass of the retaining wall and the overturning thrust of the earth is 1 foot 2 inches nearly from the front face. The whole pressure may be supposed to be distributed over the base to a thickness of three times the distance of the centre of pressure to the edge about which wall would have a tendency to overturn; in this case this would be 14 in. $\times 3 = 42$ in.

Then the average pressure per square inch of the retaining wall upon the area pressed will be the weight of the retaining wall divided by the area pressed in square inches.

$$\text{Weight of retaining wall} = 23 \times 1 \times \frac{6+2}{2} \times 170 = 15640 \text{ lbs.}$$

$$\text{Area pressed} = 3 \times 14 \times 12 = 504 \text{ square inches.}$$

$$\therefore \text{Average pressure per square inch} = \frac{15640}{504} = 31{\cdot}032 \text{ lbs.}$$

$$\therefore \text{Maximum pressure} = 2 \text{ average pressure} = 2 \times 31{\cdot}032 = 62{\cdot}064 \text{ lbs.}$$

The lowest crushing value for granites is given by Rankine as 5,500 lbs. per square inch; the pressure therefore on the base is well within the limit of safety.

SKEW ARCHES.

Necessity.—Where it is necessary to have two roads at different levels, one crossing the other at any angle other than a right angle, a skew arch, if in masonry or brickwork, becomes necessary. This differs from the ordinary arch, in that the bed-joints are not parallel to the abutments but are placed as nearly as possible at right angles to the face of the arch, for if they were placed parallel it is apparent that a large portion of the arch would have no abutment on one side and thus would fail. Under these conditions the bed-joints form winding surfaces similar to a screw thread, forming a helical coursing surface.

Projection.—A few simple geometrical problems require to be known to understand the construction of a skew arch. Skew arches are invariably formed as portions of a cylinder, and the faces of the arch may be conceived as the projections of sections made by two vertical cutting planes passing through the semi-cylinder at an angle other than 90 degrees to its axis.

It will be necessary to develop the portion of the cylindrical surface between the two cutting planes. Figures 214 and 215 show the method of performing this operation. Figure 214 shows the plan and elevation of the cylinder with the two cutting planes passing through. The elevation of the cylinder is divided into six equal parts, the projections of these points are drawn in plan and intersect the cutting planes at 0, 1, 2, 3, 4, 5, 6. To obtain the development of the surface between the planes, the surface of the cylinder must be stretched out on a plane surface and the perpendicular distance between 0 and 6 drawn as shown in figure 215. The stretch out must be divided into six parts to correspond to the divisions on the cylinder; projectors must then be drawn from the points 0, 1, 2, 3, 4, 5, 6 in plan

Fig. 216. Fig. 217.

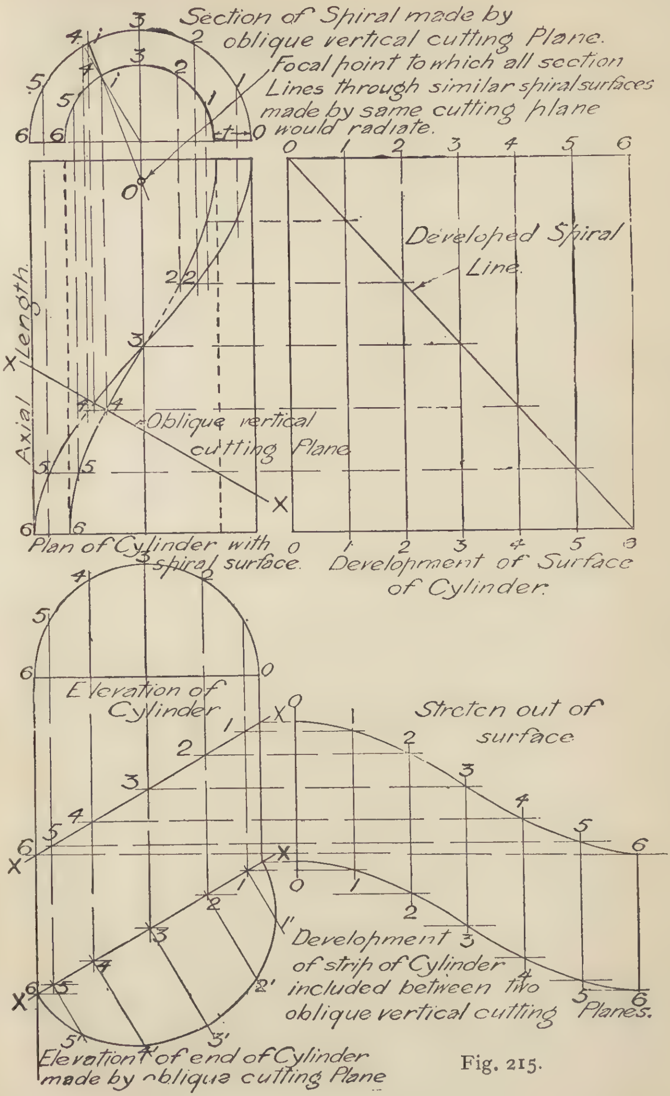


Fig. 215.

Fig. 214.

till they intersect the divisions 0, 1, 2, 3, 4, 5, 6 respectively, on the stretched out surface; then, if these points of intersection are joined by lines, the surface between these is the development of the portion of the cylinder between the cutting planes.

Figure 214 shows the method of obtaining the section of the cylinder made by one of the cutting planes.

Where the projections intersect the cutting planes in plan, erect perpendiculars, and measure the heights of 1, 2, 3, 4, 5, from the elevation and mark them off respectively on the perpendiculars; join these points, and the resulting elliptical curve is the elevation of the cylinder seen at right angles to the cutting plane.

Helical Surface.—Helical surfaces similar to helical coursing surfaces and helical heading surfaces may be drawn as shown in figures 216 and 217. Figure 216 shows the plan and elevation of a cylinder with a thickness *t*. Divide the two cylindrical surfaces into six equal parts, 0, 1, 2, 3, 4, 5, 6, and draw the projections of these points in plan; by the side of the plan draw figure 217, which may be the developed surface of the inner or outer cylinder, in this case the outer cylinder. Divide this surface into six equal strips and cut off from it a length equal to half of a complete revolution and known as the axial length, as shown in figure 216. Draw a diagonal from 0 to 6, figure 217; this will be a developed spiral line; from the points of intersection of this diagonal and the projectors 0, 1, 2, 3, 4, 5, 6, draw projectors to cut the corresponding projectors in plan; join these points in plan, and a spiral or helical surface is depicted. In figure 216 the plan of a vertical cutting plane, X X, is shown oblique to the axis of cylinder. This cuts the helical surface in the points I I. Project these points to the elevation till they cut the inner and outer cylinders respectively, join I′ I′ in elevation and produce till it cuts

the centre line in O, this point, O, is the centre from which all the chords of all face-joints of similar helical surfaces cut by the same cutting plane would radiate.

Face-Joints.—To determine the direction of face-joints in elevation taken parallel to face of arch. These face-joints will all be parts of curves, owing to the face of arch cutting the spirals at an angle other than at right angles to axis of cylinder. It will be noted that the chords of these small arcs will all radiate from some point, N, figure 220, some distance below the springing of arch. The distance M N will increase with the angle of obliquity of bridge with road. This distance M N = r cot θ tan α, or (r + e) cot θ tan ϕ. This may be proven as follows. From figure 219 draw $\frac{ZP}{YZ}$, which = the tangent of α.

$$XZ = e \operatorname{cosec} \theta$$
$$YZ = e \cot \theta$$
$$\frac{ZP}{YZ} = \tan \alpha$$
$$ZP = e \cot \theta \tan \alpha$$

Figure 220 represents the elevation of arch parallel to face. Let the values of Z X P be taken from figure 219. From point P draw P X and produce it to cut M N at N, then M N will equal the distance below the springing of arch from which all the face-joints must be drawn.

$$XZ : PX :: XM : MN$$
$$MN = \frac{PZ \times XM}{XZ}$$

Computation.—For the purposes of constructing skew arches it is better to determine the dimensions by calculations than from drawings, as any small inaccuracy in drawing would amount to an error of appreciable quantity if measured from a drawing of small scale, as all such cases must of necessity be drawn. The necessary dimensions may be computed mathematically for all parts with

accuracy. Figures 218 to 221 are explanatory of the required calculations.

Figure 218 shows plan and elevation of a semi-circular arch crossed by a road at an angle of θ with its axis.

Let r = radius then $2r$ = the span
θ = angle of obliquity of bridge with centre line of road
$2r \operatorname{cosec} \theta$ = the oblique span
$2r \cot \theta$ = the length of obliquity of arch
πr = the width of the development of intrados
CD = the development of heading spiral
ϕ = angle of heading spiral with the developed width of the intrados
$\tan \phi = 2r \cot \theta$ divided by πr
W = width of bridge

Let a line be drawn at right angles to the heading spiral (C D), cutting D E at E; this is the development of the spiral of the intrados. At E draw a line at right angles to D E, to cut B C produced in F.

Then F C is the axial length of the spiral of intrados and $= \pi \text{ r} \cot \phi$.

C I = length of impost and = W $\operatorname{cosec} \theta$.

Figure 219 shows plan and elevation of the same arch with the development of extrados.

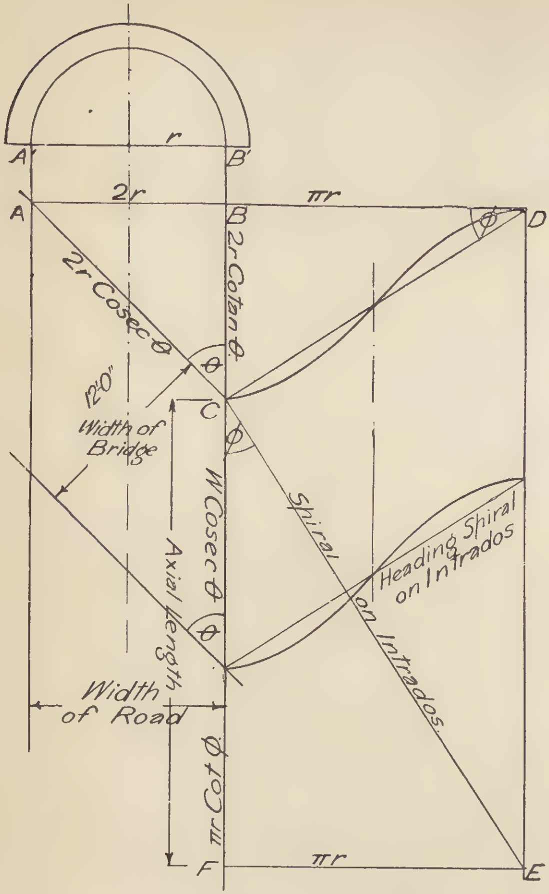
Let E = thickness of the arch
LK = width of the development of extrados and $= \pi (r + e)$
ZK = development of heading spiral on extrados
YG = CF = the axial length
YH = the spiral of extrados
α = angle of spiral on extrados with the impost and its value

$$= \tan \alpha = \frac{\pi (r + e)}{\pi r \cot \theta}$$

that is, $\dfrac{r + e}{r \cot \theta}$

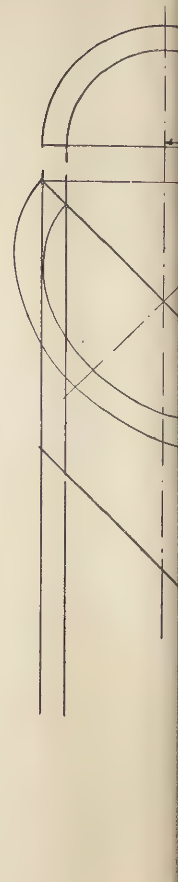
The distance M N may be determined graphically as shown in figure 221. Draw the elevation of the semi-cylinder, and from the centre draw a line passing through

Fig. 218.



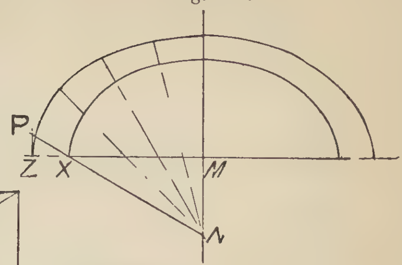
Development of Intrados
and coursing ana heading Spirals

Fig. 2

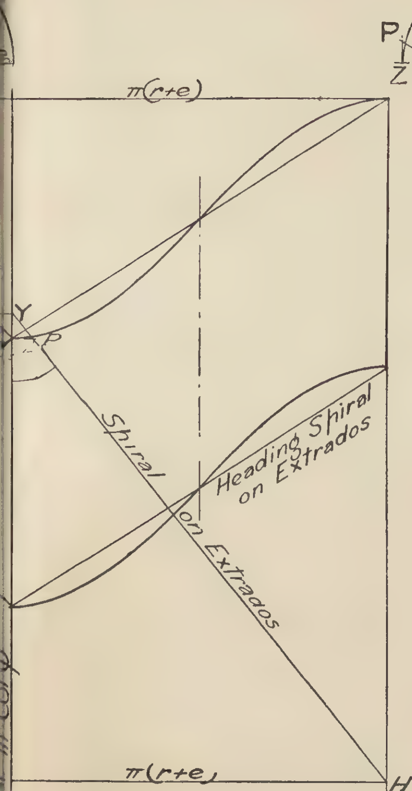


D
and

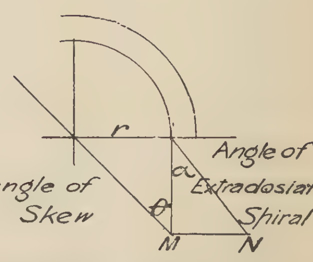
Fig. 220.



Elevation of Face of Arch



...ment of Extrados
...ing and heading Spirals



Method of graphically determining the point below the axis of cylinder to which the chords of face joints radiale

Fig. 221.

[*Between pages* 314 *and* 315.

Fig. 222.

Fig. 223.

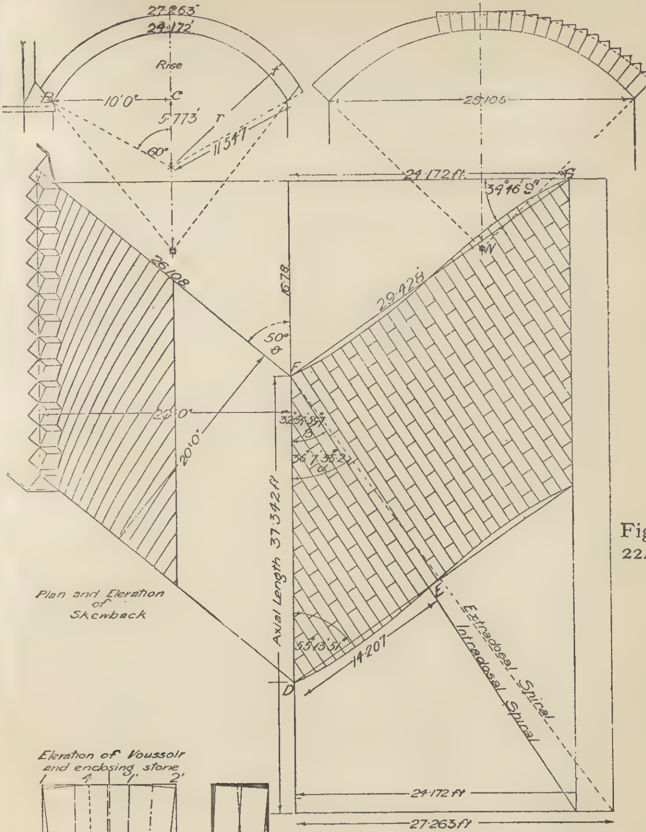
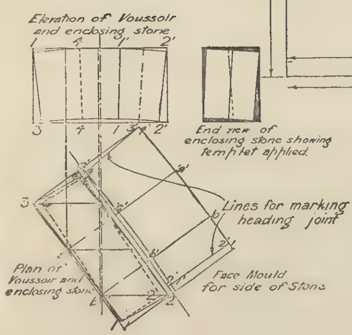


Fig. 224.



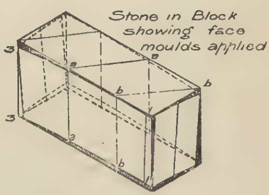


Fig. 226.

Fig. 225.

the axis, making the angle θ (that is, the angle of obliquity) with the same, till it cuts the impost line in M ; at the point M set out a line M N at right angles to the impost. From the point X draw a line X N, making the angle α (that is, the angle of extradosial spiral) with X M, cutting the line M N in N ; then the line M N equals the distance below the centre M of the point N, to which the chords of all the face-joints will radiate.

The difference between ϕ and α equals the angle of the twist for working the bed-joints, the actual values can be obtained for any particular length of stone by the formula

$$\frac{\chi}{l} = \tan \delta$$

$$\chi = l \tan \delta$$

Let χ = the amount of twist for any given length
l = length of stone
δ = difference between ϕ and α, the angles of coursing spirals between intrados and extrados.

Segmental Arch.—Let it be required to construct a bridge 20 feet wide over a road with a width of 20 feet, the faces of the bridge making an angle of 50 degrees with the centre line of the road. The arch to be segmental with an arc subtending an angle of 120 degrees, depth of arch to be 1 foot 6 inches.

First determine the radius r; then from figure 222, $\frac{c}{a}$ = cosec 60 degrees.

$$\text{therefore } c = a \text{ cosec } 60^\circ$$
$$c = 10 \times 1{\cdot}1547$$
$$c = 11{\cdot}547 = \text{radius of arch.}$$

Then determine the rise—

$$\frac{b}{a} = \cot 60^\circ$$
$$b = a \cot 60^\circ$$
$$b = 10 \times {\cdot}57735$$
$$b = 5{\cdot}7735$$
$$= \text{rise} = c - b = 11{\cdot}547 - 5{\cdot}7735 = 5{\cdot}7735$$

$$\begin{aligned}\text{The oblique span} &= s \operatorname{cosec} \theta \\ &= 20 \operatorname{cosec} 50^\circ \\ &= 20 \times 1{\cdot}3054 \\ &= 26{\cdot}108 \\ \text{The obliquity of arch} &= s \cot \phi \\ &= 20 \cot 50^\circ \\ &= 20 \times {\cdot}839 \\ &= 16{\cdot}78.\end{aligned}$$

Length of intrados equals radius multiplied by value of arc of 120°; from the tables this will be $11{\cdot}547 \times 2{\cdot}0943 = 24{\cdot}172$. Length of extrados is obtained in a similar manner. Then the radius of the extrados will $= (r + t)$, that $= 11{\cdot}547 + 1{\cdot}5 = 13{\cdot}047$; then the length of the arc $= 13{\cdot}047 \times 2{\cdot}0943 = 27{\cdot}263$.

The Angle of Coursing Spiral.

$$\tan \phi = \frac{\text{obliquity of arch}}{\text{length of arc}}$$

$$= \frac{16{\cdot}78}{24{\cdot}172}$$

$$\text{therefore } \phi = 34^\circ\ 46'\ 9''.$$

$$\text{Length of heading spiral will} = \frac{\text{heading spiral}}{\text{obliquity of arch}} = \operatorname{cosec} \phi$$

$$\begin{aligned}\text{heading spiral} &= \text{obliquity of arch} \operatorname{cosec} \phi \\ &= 16{\cdot}78 \times \operatorname{cosec} 34^\circ\ 46'\ 9'' \\ &= \log 16{\cdot}78 \quad 1{\cdot}2247920\end{aligned}$$

$$\text{L cosec } 34^\circ\ 46'\ 9'' \qquad \frac{10{\cdot}2439729}{11{\cdot}4687649}$$

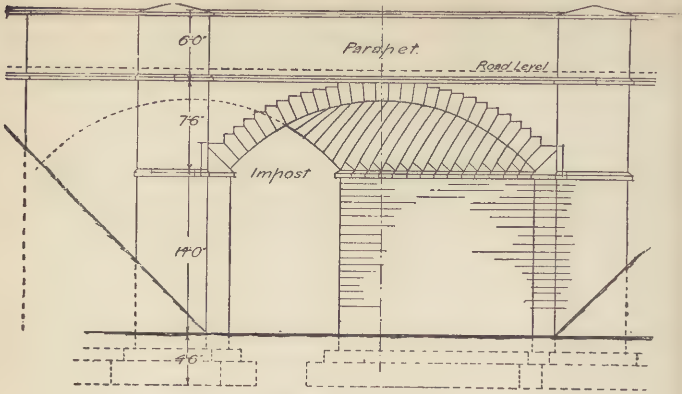
$$29{\cdot}428.$$

Let the number of voussoirs be, say, 29.

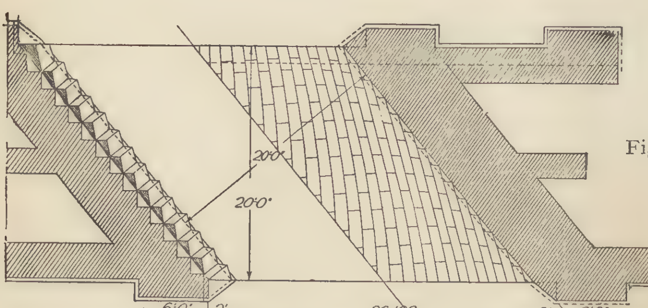
The thickness of the voussoirs (the heading spiral $\div$ 29) $= \dfrac{29{\cdot}428}{29} = 1{\cdot}0148$ feet.

The angle of intradosial spiral ϕ, which should theoretically be at right angles to the heading spiral, must be modified in order that it may correctly intersect the face-joint on opposite face of arch as each set of face-joints must be similar in elevation. Let the intradosial spiral intersect the fifteenth

Fig. 227

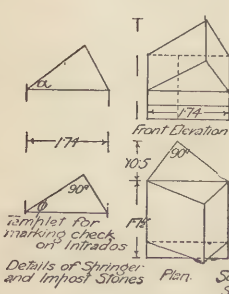


Elevation of Arch.



Half-Plan at Springer Level Half-Plan looking up

Fig. 228.



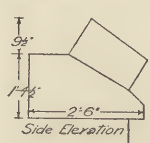


Fig. 230.

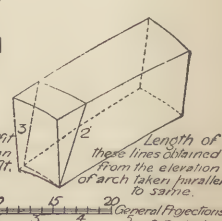


Fig. 229.

Fig. 231.

bed-joint (that is, $14 \times 1{\cdot}0148$) which $= 14{\cdot}2072$ feet from springing.

The intradosial angle now altered from ϕ to β, in the triangle DEF, figure 224,

$$\begin{aligned}
D &= 55^\circ\ 13'\ 51'' \\
E + F \text{ will} &= 180^\circ - 55^\circ\ 13'\ 51'' = 124^\circ\ 46'\ 9'' \\
\text{and } \tan\frac{E - F}{2} &= \frac{e - f}{e + f}\cot\frac{D}{2} = \frac{11{\cdot}901}{40{\cdot}315} \times \cot 27^\circ\ 36'\ 55{\cdot}5'' \\
\frac{E - F}{2} &= 29^\circ\ 28'\ 4{\cdot}8'' \\
E - F &= 58^\circ\ 56'\ 9{\cdot}6'' \\
E + F &= 124^\circ\ 46'\ 9'' \\
2E &= 183^\circ\ 42'\ 18{\cdot}6'' \\
E &= 91^\circ\ 51'\ 9{\cdot}3'' \\
2F &= 65^\circ\ 49'\ 59{\cdot}4'' \\
F &= 32^\circ\ 54'\ 59{\cdot}7''
\end{aligned}$$

therefore intradosial angle $\beta = 32^\circ\ 54'\ 59{\cdot}7''$.

Distance of the point N, towards which the chords of all the face-joints converge, from M will equal—

$$\begin{aligned}
&(r + t)\cot\theta\tan\beta \\
&(11{\cdot}547 + 1{\cdot}5)\cot 50^\circ \times \tan 32^\circ\ 54'\ 59{\cdot}7'' \\
\log 13{\cdot}047 &= 1{\cdot}1155107 \\
L\cot 50^\circ &= 9{\cdot}9238135 \\
L\tan 32^\circ\ 54'\ 59{\cdot}7'' &= \frac{9{\cdot}8111142}{20{\cdot}8504384} \\
Mn &= 7{\cdot}0866 \text{ feet.}
\end{aligned}$$

To determine the axial length:

$$\begin{aligned}
\frac{\text{Axial length}}{\text{length of arc}} &= \cot\beta \\
\text{Axial length} &= \text{length of arc} \times \cot\beta \\
&= 24{\cdot}172 \times \cot 32^\circ\ 54'\ 59{\cdot}7'' \\
\log 24{\cdot}172 &= 1{\cdot}3833126 \\
L\ \delta\cot 32^\circ\ 54'\ 59{\cdot}7'' &= \frac{10{\cdot}1888858}{11{\cdot}5721984} \\
&\ 37{\cdot}342 \\
\text{Axial length} &= 37{\cdot}342 \text{ feet.}
\end{aligned}$$

To determine the extradosial angle α:

$$\frac{\text{length of extrados}}{\text{axial length}} = \tan \alpha$$

$$\frac{27{\cdot}263}{37{\cdot}342} = \tan \alpha$$

$$\log 27{\cdot}263 = 1{\cdot}4355736$$
$$\log 37{\cdot}342 = \underline{1{\cdot}5721984}$$
$$\bar{1}{\cdot}8633752$$
$$\text{L} \tan \alpha = 10 + \bar{1}{\cdot}8633752 = 9{\cdot}8633752$$
$$\alpha = 36^\circ\ 7'\ 35{\cdot}2''.$$

To determine the angle of twist or δ:

δ or the angle of twist = extradosial angle − intradosial angle
" " " " " $= 36^\circ\ 7'\ 35{\cdot}2'' - 32^\circ\ 54'\ 59{\cdot}7''$
" " " " " $= 3^\circ\ 12'\ 35{\cdot}5''$.

To determine the twist for a stone of given length.

Let X = the twist in any given length and l = the length $= 3'\ 0''$

$$\frac{X}{l} = \tan \delta$$
$$X = l \tan \delta$$
$$X = 3 \tan 3^\circ\ 12'\ 35{\cdot}5''$$
$$\log 3 = 0{\cdot}4771213$$
$$\text{L} \tan 3^\circ\ 12'\ 35{\cdot}5'' = \underline{8{\cdot}7488168}$$
$$9{\cdot}2259381$$
$$\underline{10\qquad\qquad}$$
$$\bar{1}{\cdot}2259381$$
$${\cdot}16824 \text{ feet}$$

$\therefore$ twist for stone $3'\ 0''$ in length $= 2{\cdot}018$ inches.

Projections of the Arch.—Figure 223 is an elevation of the face of the arch drawn parallel to the face, showing the arrangements of the face-joints and the true lengths of the bed-joints on face; these are necessary in order to cut the face of the quoin face stones. Figure 227 shows elevation of bridge parallel to the face of the arch. It may be noted that the quoin stones of the face of the arch are arranged with horizontal stepped joints: this is rendered necessary,

particularly in arches of great obliquity, as otherwise there is a tendency for the spandril to slip off the arch. In brick arches the spandril should be tied back towards the centre of the arch with iron cramps, to neutralise this tendency. Figure 228 shows the plan of the arch. One side is a half plan looking up at the soffit, the other half is a plan at the springer level showing the arrangement of the impost and the springer stones. It should be noticed that the backs of the springing stones are worked in steps, so that they may have an abutment normal to the pressure of the arch.

Cutting of Coursing Stones.—Figure 225 shows the method of producing and applying the face moulds for cutting the coursing stones. Figure 226 shows the plan and elevation of a coursing stone looking parallel to the centre line of the road under the bridge. It also shows the projections of the rectangular block of stone that would contain the coursing stone. The extradosial and intradosial surfaces are projected till they cut the sides of the enclosing block. The form thus delineated is the face-mould to be applied to the side of the stone, and is shown in the auxiliary elevation in figure 226. The ends of the coursing stone are produced till they cut the ends of the enclosing stone, and in a similar manner the form delineated in the templet for the end of the stone as shown in the end view, figure 226. The end view shows the bevil (calculated from the angle of twist) applied, and the templet for the end. Figure 225 is an isometric view of the block of stone, showing the end and side face moulds in position. To work the stone it is necessary to remove the superfluous stone shown by shaded lines; this will form the intradosial and extradosial surfaces. To form the bed-joints two parallel strips of zinc are required, one the width of the extrados of the stone, the other the width of the intrados; these are placed one on the bottom and

top respectively, and so that their edges coincide with the angles of the ends of the templets. A line must be drawn along each edge, and on the removal of the superfluous stone the bed-joints will be formed.

Face Stones.—Figure 231 is an isometric view of a coursing stone to be used at the quoins. To obtain the lines to give the face of the stone, proceed as follows: (1) mark the soffit, the bevil for which can be obtained from the developed soffit; and from the extremities of the line thus obtained draw the side joints, the lengths for which can be obtained from the elevation of the arch, figure 223. Join these lines on the extrados and remove the superfluous stone; this will give the face for the first voussoir from the springing.

Springer Stones.—Figure 229 shows the templets for marking the check on the springer stones. The templet for intrados is obtained as follows: There are fifteen stones in the impost, the length being 26·1008 feet ÷ 15 = 1·74 feet; this gives the length of the base line of the templet. From one extremity set up a line making an angle ϕ with base, from the other extremity set up a line making a right angle with the last line drawn, the triangle thus obtained will be the templet of the intrados. The templet for the extrados will have a similar length of base; draw this base line immediately over the preceding base line and draw a line from the apex of the first triangle till it intersects a line drawn with angle α from that end of the base which corresponds with the angle ϕ of the first triangle, as shown in figure 229. Figure 230 shows plan, elevation and side elevation of a springer stone fully dimensioned.

STONE STAIRS.

Stone stairs consist of a number of blocks, fixed at regular and convenient heights, to facilitate transit between planes of different levels, and are of three kinds: (1) Those stairs supported at both extremities; (2) those fixed at one end (the other end being left free), and known as hanging steps; (3) steps circular in plan. These latter are divided into two classes: (1) Those with a central newel; (2) those with an open well.

Sections of Steps.—The steps may be in one of two forms, either rectangular or spandrel, as shown in figure 232. In the commoner stairs the rectangular blocks are used, but where a good appearance is desired, or to gain headroom, spandrel steps are employed. The spandrel steps may be finished in one of three ways: (1) with a plain soffit, which consists in finishing the soffit in one plain surface, as shown in figure 232; (2) a broken soffit may be employed, as shown in figure 232 (this is used for one of three reasons, or for all combined: (*a*) to gain strength at the back of the tread; (*b*) to save the expense incurred in working the surface of each step perfectly level; (*c*) to obtain effect); (3) having the soffit moulded.

Each step may simply rest upon the one below it, but it is usual for the upper step to be rebated over the back of the one below to prevent sliding. To avoid acute angles at this point and to form an abutting surface, particularly in the spandrel steps, a chamfer is taken off the top back edge of the lower step at right angles to the pitch of the stairs, the upper step having a corresponding sinking to fit. This is known as a back joint, and is shown in figure 232.

Fixing the Steps.—Stone stairs are erected in one of two ways: (1) They may be built in the walls as the latter are built, or (2) spaces may be left in the walls to receive

the ends of the steps, which are fitted and fixed when the wall is finished. The wall should be built in cement mortar, for at least 12 inches above and below the line of the stairs, the gaps to receive the stairs being temporarily filled up by brickwork bedded in sand.

The ends of the steps should be pinned in the walls from $4\frac{1}{2}$ inches to 9 inches with tiles or slates set in cement, care being taken that the space left about the end of the step is filled up, as far as possible, with solid material, leaving no thick mortar joints to squeeze out. While the step is setting, the outer or free end should be supported with wood struts, after being levelled, which should remain until the cement has thoroughly set.

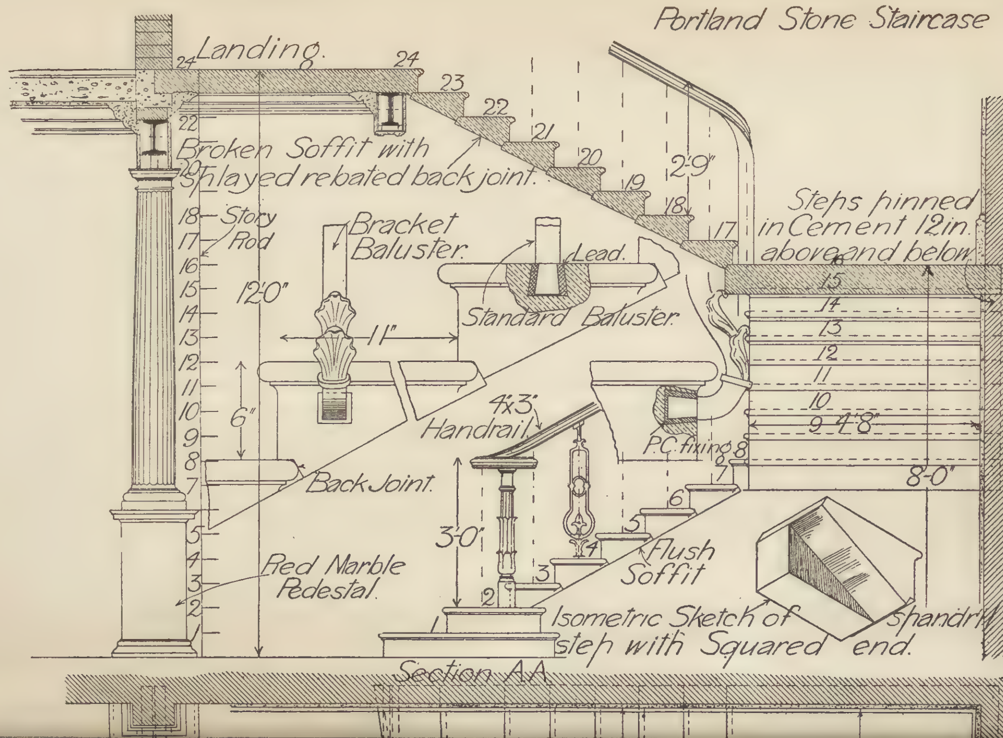
Steps supported both ends.—The first kind of stair, viz., those supported at both ends, combine convenience with the greatest strength. They are much used in schools, theatres, and other public buildings. They are usually made of rectangular steps, which rest 6 inches on the wall at either extremity.

Hanging Steps.—The second kind, or hanging steps: these are much superior in appearance to those last described. They derive their chief support from the walls, but each step receives an additional amount from the one directly beneath it. These are used for all conditions of stairs, from the secondary staircases in dwelling-houses to the grand staircases in public buildings. In the commoner kinds, rectangular steps are used; but in the superior, spandrel steps are always employed.

The steps may be plain or have moulded nosings; where the latter are employed, the moulding should be returned about the free end, the moulding on the latter being returned and stopped directly beneath the riser of the steps above, as shown in figure 232.

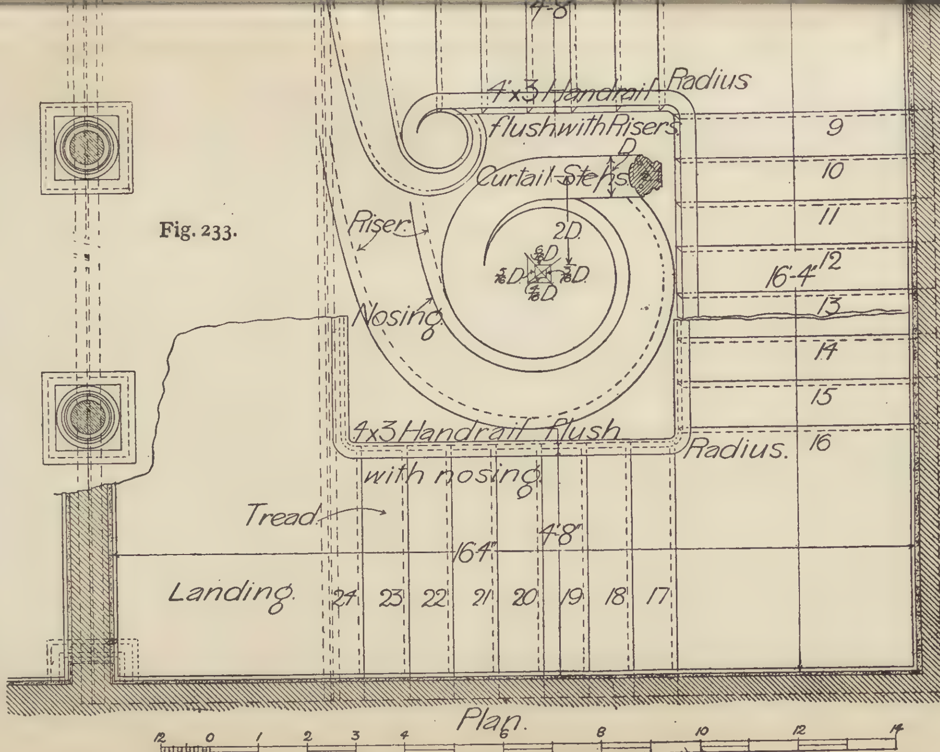
When the staircases are very wide, it is advisable to

Fig. 232.



Portland Stone Staircase
Landing.
Broken Soffit with Splayed rebated back joint.
Story Rod
12'0"
Bracket Baluster.
Lead.
Standard Baluster.
11"
6"
4"x3" Handrail.
Back Joint.
Red Marble Pedestal.
3'0"
2'9"
Steps pinned in Cement 12in. above and below.
P.C. fixing
4'8"
8'0"
Flush Soffit
Isometric Sketch of step with Squared end.
Shandril
Section AA.

Fig. 233.



Figs. 232—233.

[*Between pages 324 and 325.*

support the steps at their outer ends by iron joists or cantilevers at intervals, the strength of stone under cross stress not being very great. Figure 232 shows a landing supported by a joist.

Turret Steps.—The first of the third class of stair, the circular newel, is used for turret steps; they are built in a circular chamber. The steps are wedge-shaped, their thin end being worked circular to a radius of about 3 inches, the front edge of each step being tangent to this circle, the back edge of the step being a radial line. The steps are built into the walls of the chamber, at their wide ends, each of the circular ends being arranged to fall directly over the one beneath it, thus forming a continuous newel up the centre. These form a strong stair, but are rather dangerous, as they have to be steeply pitched to gain the necessary headroom.

Circular Staircases.—Secondly, those formed with an open well are built in the same manner as the hanging stair, of which they form one variety. Stairs, circular and elliptical in plan, are often built between two walls, as in the first class of stair.

Large stone landings which cannot be obtained out of one piece of stone are joggled at their joints, as shown in the *Elementary Course*, and where the slabs are thin, and are likely to be subjected to heavy traffic, should be supported by iron girders.

Balusters.—The balusters in stone staircases are always of iron, which is better for fixing purposes. There are two methods of fixing balusters: (1) Fixing them into the top, suitable for standard balusters, as shown in figure 232; (2) fixing them into the side, when they are termed bracket balusters; as shown in figure 232. Holes are bored in the steps at the proper intervals, being slightly undercut. The

ends of the balusters are indented before being inserted; they may be fixed in with lead, Portland cement, sulphur and sand, or asphalte, as previously described.

Figures 232 and 233 show plan, elevation, and details for an open well hanging stair, built of Portland stone. The lower flight shows handrail supported by standard balusters, the upper portion with bracket balusters to obtain the maximum quantity of available stair space. The method of setting out a scroll and curtail step is shown.

Specification of Mason's Work (*Edinburgh Practice*).—The following may be taken as a typical specification in a stone district :—

Excavations.—The whole of the surface soil for 12 inches deep to be excavated under the site of the building and carted away to a place of deposit to be found by the contractor.

Tracks.—The tracks of all walls to be excavated to the sizes shown on plan, or 15 inches wider than thickness of walls and in depth until a solid foundation is obtained, the surplus after what is required to fill in around walls to be carted away.

Foundations.—The foundation course to be of hard solid, flat bedded stones, not less than 8 inches thick, hammer dressed on beds and squared on joints laid solid in lime mortar and full breadth of wall in single stones, each stone to be at least 12 superficial feet.

The foundations for partitions and the inner walls to be as already specified 6 inches thick, but every stone across wall in one stone, and at least from 2 to 3 feet long.

Rubble.—The walls to be built of good sound rubble stones from a quarry approved by the architect in writing before the work is begun, the main stone walls to be 2 feet

6 inches thick up to underside of sleeper joists, and 2 feet above them.

The partition walls to be 15 inches thick up to the level of sleeper joists, and sleeper walls to be 12 inches thick, all built and bonded throughout with headers in every course and not more than 5 feet apart. The walls to be carried up not more than 15 inches at a time, the whole to be levelled at the underside of sleeper joists for asphalte.

Asphalte.—Damp courses to all walls ½ inch thick, composed of best British pitch, Stockholm tar, and washed kiln-dried gravel, spread on walls while hot without cracks, and built on immediately after laying to prevent breaking; the internal walls to be covered with boarding to prevent being destroyed until they are to be built on. The whole area of building under wood floors to be levelled up with stone shivers to about 12 inches from underside of the sleeper joists, hard beaten down and rammed all round walls, the stone coating to be at least 6 inches thick. The whole to be covered over with a ¾ inch coat of asphalte as previously described free from cracks. To prevent injury to the asphalte, this is to be laid after the building is up preparatory to the fixing of the ground floor joists.

External Face Snecked Rubble.—The external face of walls to be built of split-faced or natural-faced rubble work having no tool marks on the face, squared on the joints and beds with mallet and chisel, the full thickness of stone, not less than 8 inches thick, having headers not more than 5 feet apart. No stones to be higher than 8 inches nor less than 3 inches, nor more than three times their height in length nor less than twice their height, nor must more than three heads come together. The joints and beds to be ½ inch, and neatly set to this; the building mortar to be kept back 1¼ inches from face for pointing afterwards.

Pointing.—The faces of walls to be pointed with cement and sand after the buildings are completed, the proportion being three of sharp sand to one of best Portland cement, properly mixed on a board, the beds and joints being well damped before the mortar is used, and the latter pressed in hard with a $\frac{3}{8}$ inch iron key, and sunk in, as shown in figure 207 E in my *Elementary Course.*

Inside of Walls.—The inside of these walls is to be built with good level bedded stones built cross bond throughout, and backed up to outside face every 15 or 18 inches in height, and grouted up with lime grout every time they are levelled.

Scontions.—The scontions at inside angles or outside corners under ground level to be of large-sized stones, say 20 inches long, 12 inches thick, and of heights to suit outside hewn work at openings where they connect. Scribbled on beds and faces wrought to the shapes required, including bay on sides of windows, and properly bonded with rubble walls.

Hewn Work: Corners.—The corners to be of sandstone from Prudham Quarry of the best liver rock, average length 20 inches, thickness to average in height from 8 inches to 12 inches, squared and chiselled on beds and joints, and finely scabbled or tooled on face diagonally, to have seven tool marks to every inch, set in fine lime and pointed with cement mortar when the rest of walls are being pointed. The beds to be $\frac{3}{16}$ inch thick.

Window Sills.—The window sills to be of same stone as corners, 14 inches broad and 9 inches thick, scabbled as corners, on exposed surface, weathered and throated and reprized for rybats having 9 inches longer on each end than daylight of windows.

Rybats.—The rybats of windows to be same stone as for corners, and scabbled as specified for corners. The inbans in 2 feet walls to go right through the walls, and to be

12 inches on heads checked for window cases and moulded on angle. The outbans to average 20 inches long and 10 inches on heads checked for window cases, and moulded on angle, the moulding average 8 inches girth. The height of the rybats to average 8 inches to 12 inches in various heights, set in fine lime and pointed with cement mortar along with the rest of the walls.

Lintels.—The lintels of outside openings to be of similar stones to the corners, and scabbled on exposed parts, to be 9 inches longer on each end than daylight of opening, 14 inches high and 12 inches thick, checked for window case on inside angle and moulded, and reprized to suit rybats on outside angle, set in fine lime and pointed as before.

Mullions.—These stones, as before, in single lengths and 7 inches × 7 inches, moulded as rybats on two angles, dowelled with slate dowels 2 inches × 1 inch to sills and lintels.

Saves.—The lintels over all voids to be saved with long rubble stones meeting in centre, or joined with a key stone between; these saves to be broad on beds and of heights to match face work chiselled on beds and joints, and as face work on their seen faces.

Arches.—The inside of window openings to be arched with 9 inch brick arch set in cement, having stone springers shaped to the proper radius; in case of wide windows the inside to be lintelled over with two rolled steel joists, 8 inches × 6 inches, covered on top with flat stones 5 inches or 6 inches thick, and full breadth from inside face of wall to back of outside lintel, close jointed.

Base Course.—The base course of similar stone as the corners, 14 inches broad and 9 inches high, scabbled where exposed, splayed on angle and tooled, squared on joints close set and pointed as before.

String Course.—To be 14 inches × 6 inches moulded on projection and tooled; girth of tooled work 12 inches, weathered on top 4 inches.

Skews.—The skews to be 18 inches × 6 inches, tooled where exposed, and moulded on edge and plain on inside, bedded and pointed with cement.

Skew Puts.—These to be about 30 inches long by 18 inches broad and 15 inches high, moulded and sunk on face to match skews, also on end for return, and sunk on top bed.

Ties.—In centre of height of skews tie stones about 2 feet long and 14 inches high, sunk on face with skews relieved.

Apex.—The apex stones to be about 2 feet × 2 feet × 18 inches having skews relieved on their face, sunk and scabbled, the backs sunk for slates.

Chimney Cope.—The chimneys to have moulded cope, each stone the full breadth scabbled all round 12 inches thick, with holes for vents cut through the solid 10 inches diameter, and batted with iron bats at joints sunk below flush, filled in and covered with cement.

Cans.—Red chimney cans 2 feet 6 inches high, moulded and tapered, sunk 2 inches to cope, and filleted all round with cement.

CHAPTER V.

CARPENTRY.

Definition.—Carpentry is the art of framing timber for structural work, and may be divided under two heads—(*a*) temporary, (*b*) permanent.

(*a*) Temporary work includes the timbering for excavations, the erection of scaffolds, gantries, shoring, and the construction of centres and all works raised for the convenience of the workman in building the permanent erection; which are removed on the completion of the building.

(*b*) Permanent work includes all timbering that forms part of the structure, such as wood floors, partitions, half-timbered work, and roofs which remain on the completion of the building.

TEMPORARY WORK.

Classification.—The temporary work will be considered under the following heads:—(1) The timbering for excavations, (2) scaffolding, (3) gantries, (4) centering, (5) shoring.

The timbering for excavations has been described in the chapter on Foundations.

SCAFFOLDS.

Definition.—Temporary erections, constructed to support a number of platforms at different heights, raised for the

convenience of workmen, to enable them to get at their work, and to raise the necessary material, are termed scaffolds.

Classification.—Scaffolds are divided into two general kinds: (1) Bricklayers', (2) Masons'.

1. *Bricklayers' Scaffold.*—The bricklayers' scaffold consists of a number of uprights, called standards, placed about 8 feet apart, these being fir poles about 5 inches in diameter and 30 feet in length. The standards may be increased to any length by lashing a number of poles together; this is done as occasion requires during the erection of the building. The standards rest with their bottom ends on the ground, but to increase their stability and prevent lateral motion the ends are often embedded for about 2 feet in the ground; if any difficulty exists in doing this, a barrel filled with earth is employed to receive the end of the pole, and a York stone flag immediately beneath the standard advantageously extends the bearing surface. Similar poles, called ledgers, placed horizontally and with a vertical distance apart of 5 feet, are lashed to the building side of the standards, 5 feet being the greatest height that the average man can work with ease.

These form a frame, which is erected about 4 feet 6 inches from the face of the intended building, to which it is connected by means of horizontal members called putlogs, which take a bearing on the wall at one end, and at the other on the ledgers, to which some are lashed, these being wedged to the wall when the wall has been built sufficiently to allow of this being done.

The putlogs are of square timber, usually birch, 3 in. × 3 in. and 5 feet in length, the pieces not being cut, but split, to ensure the length fibres being uncut.

The putlogs are placed about 4 feet apart, and on them the scaffold boards are laid to form the platform. The

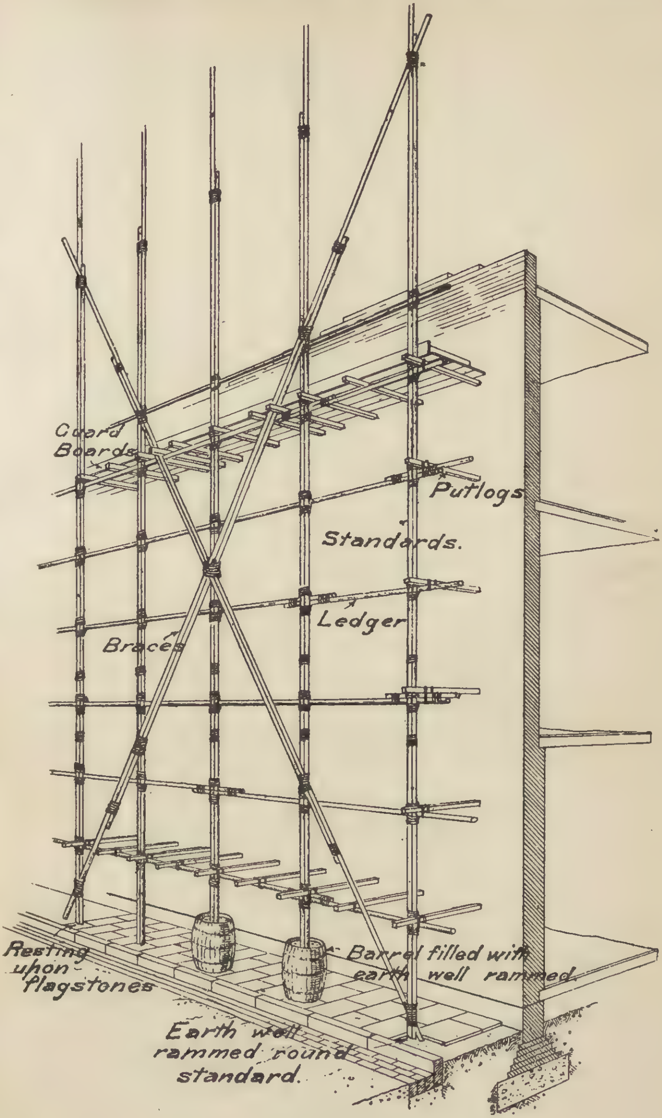

Guard Boards
Putlogs
Standards.
Ledger
Braces
Resting upon flagstones
Barrel filled with earth well rammed.
Earth well rammed round standard.

Fig. 234.

boards are 12 feet in length, 9 in. × $1\frac{1}{2}$ in.; the ends are bound in hoop iron, to prevent their splitting.

The scaffold boards at their heading joints are butted, two putlogs being placed at this part about 4 inches apart to support the ends. About the edges of the staging guard-boards are placed, consisting of boards stood on edge and nailed to the standards, as shown in figure 234, to prevent material falling.

The "London Bye-Laws" require the lowest stage to be double boarded, and guard-boards about the edges, for the purpose above stated. This staging remains until the scaffolding is taken down, but all the above stages are raised as the height of the building increases.

The frames are braced to add stiffness and to prevent the scaffold rocking, these braces consisting of poles lashed to the outside of the frames to triangulate the latter, as shown in figure 234.

For 9-inch walls a scaffold is only required on one side of the walls, but for all walls of a greater thickness a scaffold is required on both sides.

2. *Masons' Scaffold.*—Masons' scaffolds are constructed on principles similar to the bricklayers', but owing to the increased weight of the materials handled, the whole erection is made much stronger, the standards being placed closer together longitudinally and more firmly braced. Two frames are erected, one on each face of the wall and about 4 feet 6 inches distant from it. These frames are erected preparatory to the building of the wall; they are connected together by short poles, called cross ledgers, lashed to the longitudinal ledgers, and they are also braced transversely as well as on the face of the frames. These are frequently termed independent scaffolds, as they obtain no portion of their support from the wall. At each staging ledgers are lashed to the cross ledgers on both sides of and parallel to and

about nine inches from the face of the wall. These serve as the inner supports for the putlogs, being rendered necessary as the putlogs must obtain no support from the wall. The inner ledger is further stiffened by short upright poles or pieces of quarterings resting upon the ledger beneath.

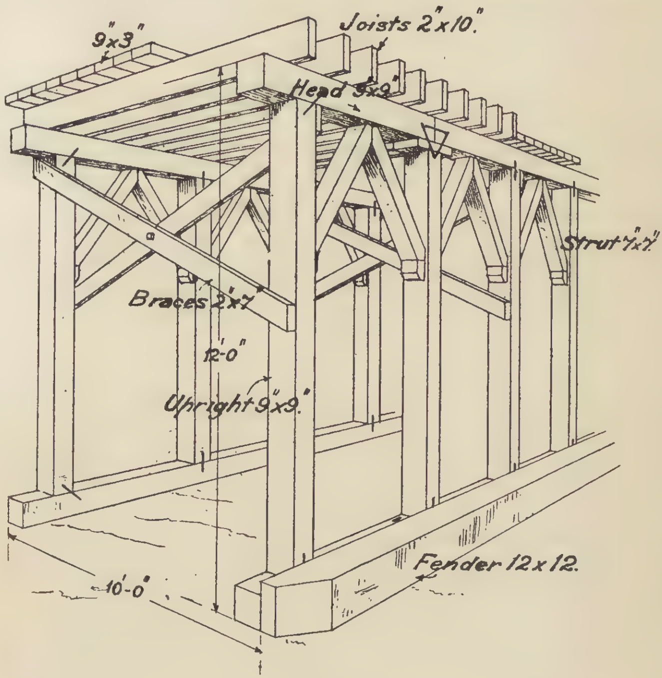


Fig. 235.

As the wall is erected the cross braces are removed, and it is frequently necessary to remove some of the cross ledgers, but the greater number should be arranged to pass through window openings to prevent the necessity for their removal.

It is usual to have scaffolds on both sides of walls for

masons' work, but in Scotland it is usual for both bricklayers and masons to work from the inside of the wall only, the materials being hoisted by means of derrick cranes. The walls are erected and the floors constructed, the latter forming platforms at these levels; any intermediate levels are constructed from platforms supported by trestles of about 5 feet in height resting on the floors. If more than one such tier or platform is required between each floor, a second series of trestles are placed on the platform immediately above the supporting trestles. In the case of large cornices, or work requiring special care in setting, a temporary face scaffold is usually projected on cantilevers. The method of building from internal scaffolds is objected to in the south of England, as it does not admit of the work being so conveniently inspected.

Gantries.

Definition.—Erections of squared timber, constructed and arranged for the manipulation and transmission of heavy weights, and also, in urban districts, as a base of operations, where the space in front of a new building is a public footway, are termed gantries.

Classification.—Gantries are divided into three classes: (1) Elevated platforms, (2) gantries to support travellers, (3) gantries to support derrick cranes.

1. *Elevated Platforms.*—These are constructed of two frames placed usually from 8 to 10 feet apart, out of square timber, ranging from 6 to 12 inches, according to the work in hand. The frames consist of a head, a sill called a sleeper, uprights and braces. The sleepers are first laid on the ground, the uprights placed in position and dogged to the sleepers, the heads are placed on the uprights and dogged in a similar manner to the sill; where a joint occurs in the head it is made to come over an upright, a short piece of deal being

placed on the top end of the latter, to increase the bearing, the whole being dogged together (as in figure 235). Braces, usually out of about 4 in. × 4 in., are cut and fixed between the uprights, the heads of the struts butting against each other or against a straining piece, their bottom ends resting on cleats nailed to the uprights; the two frames are also braced together by having braces spiked or bolted

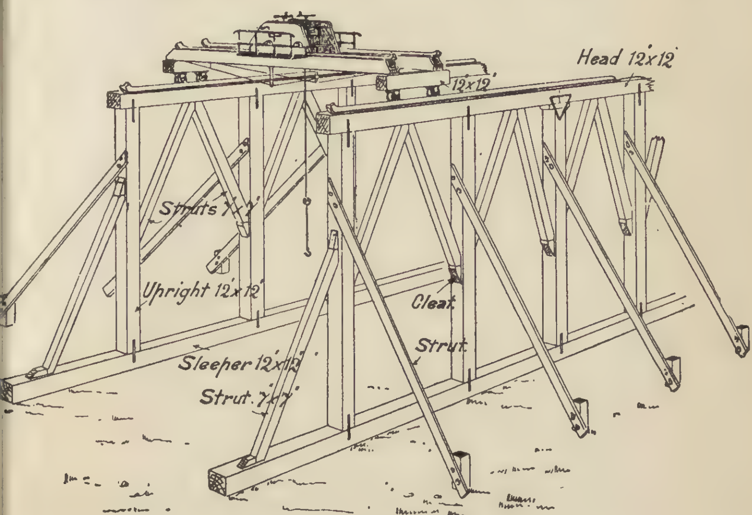


Fig. 236.

to their standards (as shown in figure 235). The platform is formed by laying deals flat, side by side, bearing on the heads of the two frames, or by placing them on edge from 1 foot to 2 feet apart, and covering them with a flooring of scaffold boards. The inner frame is kept at least 1 foot from the face of the proposed work.

2. *Gantries to support Travellers.*—These are formed of two frames, constructed in a similar manner to those described,

but as the space between the frames is required to be clear the latter can only be connected at their two ends; the frames must, therefore, be made to stand independently of each other (as shown in figure 236); these are usually made of balk timber. The members are fitted together accurately, every care being taken to make the frames rigid. Iron rails are bolted to the heads of the frames upon which the travellers move; these are turned up at the end of the gantry, to prevent the traveller moving beyond that point.

The travellers consist of two trussed beams, the arrangement of the truss varying with the span; these are connected at their extremities by short pieces of balk timber mounted upon wheels, as shown in figure 237. Rails are bolted to each of the beams on which a crab, mounted on wheels, is free to move the whole length of the trussed beams.

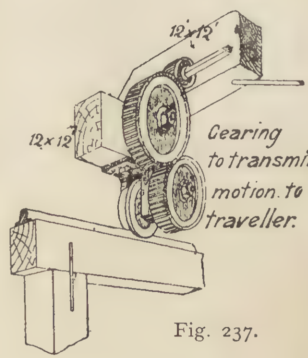


Fig. 237.

Motion is imparted by manual, steam or electric power to the traveller by means of a cog-wheel keyed on the inside of the bearings to the axle of one of the wheels upon which the traveller moves at each end of the trussed beam; these cogs are geared to another wheel keyed to a shaft of about 1½ inches square. Upon the square shaft a bevel wheel is fitted, so that it is free to slide along the bar, the wheel being connected to the movable crab by means of a projecting bracket; this cog is geared to another bevel wheel keyed to an upright shaft, which is caused to revolve by the man in charge of the crab. In consequence of this apparatus requiring to slide along the whole length of the shaft the latter has to be free from end to end; if the shaft be

long there would be a danger of it sagging; to obviate this the arrangement consists of a bearing which revolves upon an axis (shown in figure 238); this is employed to surmount the difficulty, being pushed into an inclined position when the crab passes that point.

The side frames of gantries of this description are now often dispensed with, the travelling beams being framed to two trestle-like legs, constructed as shown in figure 239, the

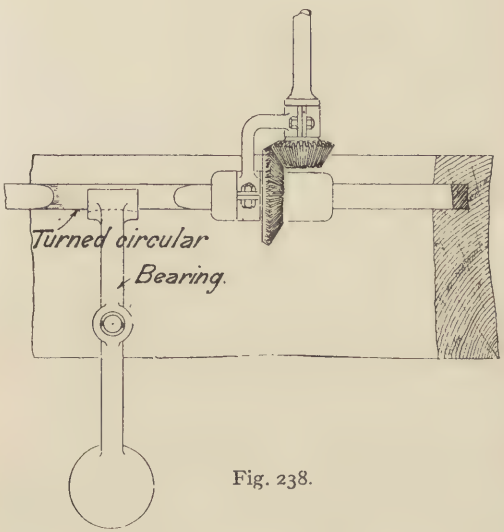


Fig. 238.

whole being mounted on wheels, which travel on rails fixed on the ground.

Gantries of this description usually have a steam winch on the traveller, motion being imparted to the latter by a similar apparatus to that described, and modified to suit the new conditions.

3. *Derrick Stagings.*—Derrick cranes are now largely used in England, owing to the facilities they offer for

transferring materials to any part of a building in process of erection, and to the great area commanded by them. They are elevated to the required height on three timber

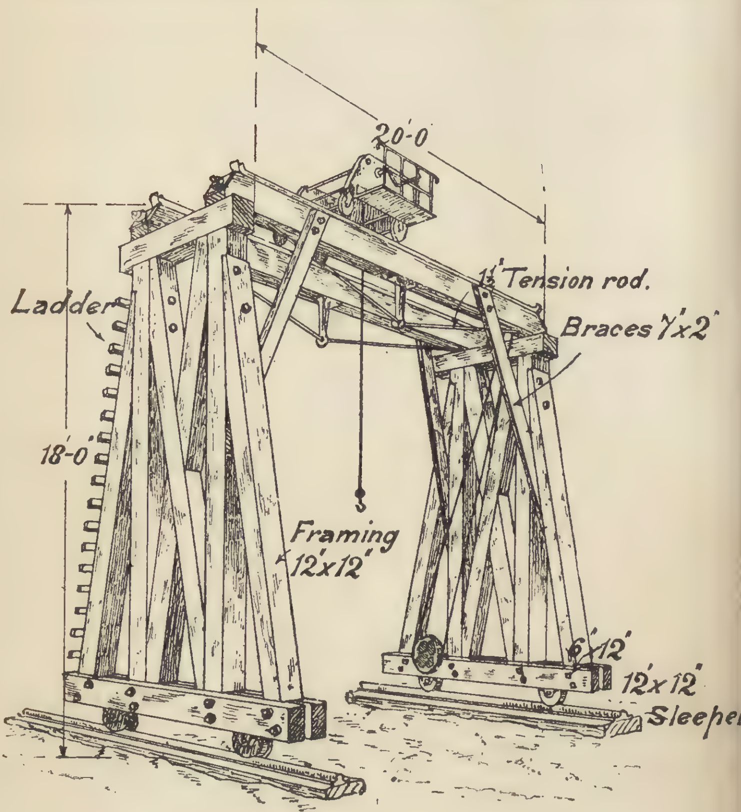


Fig. 239.

supports, or towers, the latter being constructed in one of two different ways.

Derrick Crane.—The derrick, as shown in figure 240,

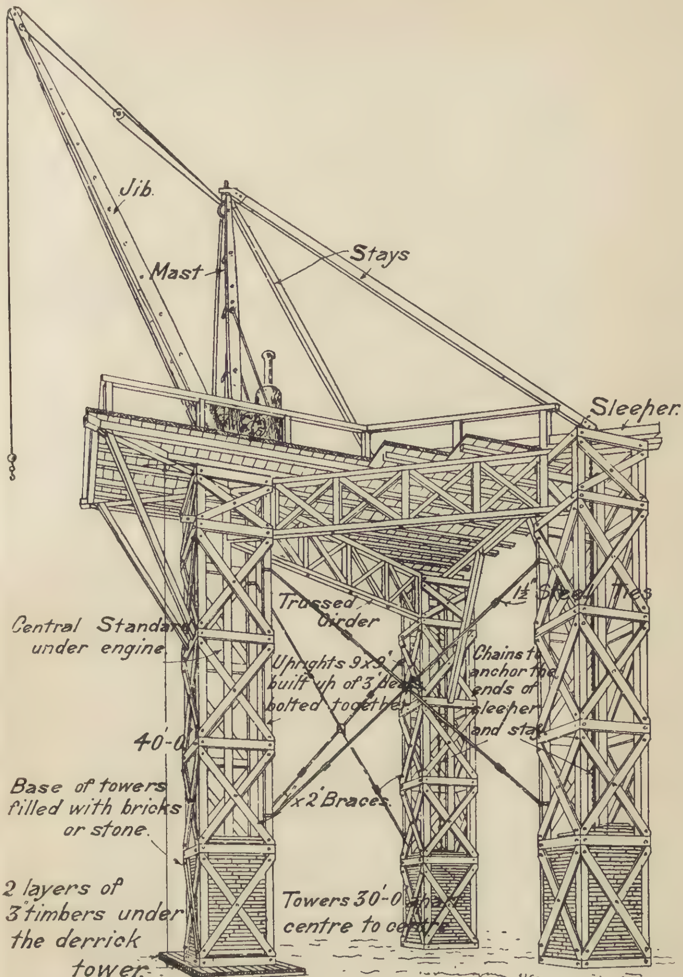

Jib.
Mast
Stays
Sleeper.
Trussed
Girder
Central Standard
under engine
Uprights 9x9"
built up of 3
bolted
Chains
anchor
ends of
and
40'-0
Base of towers
filled with bricks
or stone.
x2" Braces
2 layers of
3" timbers under
the derrick
tower.
Towers 30'-0
centre to

Fig. 240.

consists of four parts: (1) The mast, (2) the jib, (3) the sleepers, and (4) the stays.

1. *Mast.*—The mast is the upright member; this may be out of one piece of timber, or out of two pieces strutted apart and braced. This terminates in a pivot on top and bottom, which allows it to rotate freely. A short distance from the bottom is fixed the machinery for raising the materials; this may be worked by hand or steam—in the latter case the boiler and engine are attached to a platform, to which the bottom of the mast is fixed, and beneath this platform is the gearing to change the direction of the derrick in a horizontal plane.

2. *The Jib.*—The jib is the member to which the weights are hung; it may be formed of one piece of timber, or built up in a similar manner to the mast; it is attached to the mast at its lower end by a hinged joint, which allows it to work up and down, or change its direction in a vertical plane; at its other end is a wheel, over which the rope or chain that supports the weights is passed, and to this part also the rope or chain is fixed that raises or lowers the jib. Both these chains pass over pulleys at the upper end of the mast, and from there down on to the drums on to which they are wound.

3. *Sleepers.*—There are two sleepers, consisting of timbers which lie on the ground or staging; these are connected to the lower end of the mast by a swivel joint.

4. *Stays.*—The stays are similar timbers to the above, connected at their upper ends to the top of the mast by a swivel joint, and at their lower end to the free end of the sleepers by a link joint, thus forming two triangular frames.

The stays and sleepers at their junction are anchored down to the ground, or staging, to counteract the overturning tendency of the mast when the derrick is loaded.

Derrick Towers.—These, as previously stated, are built in two methods—(1) by building three timber towers, connected by trussed beams, which support the platform or stage; one of the towers is so arranged that it has the pivot of the spinning gear centrally above, the other two are arranged that with the first they form an isosceles triangle in plan, the junctions of the sleepers and the stays being placed respectively centrally above a tower; (2) by upright timbers properly braced and strutted in lieu of the towers above-mentioned, and similarly disposed as regards the remainder of the staging.

1. Each of the towers is constructed about 6 feet square in plan, and they are placed about the apices of an isosceles triangle, the distance between them varying with the available space and the length of the timber sleepers. Each tower consists of four uprights about 9 inches square, either out of solid timber or built of 9 in. × 3 in. deals bolted together, the latter being the better plan when the posts are required of a great length; these are connected together by cross-pieces or transoms, out of about 9 in. × 3 in., placed about 7 feet apart, dividing the towers into a number of bays, these being stiffened by cross braces, out of about 7 in. × 2 in. cut between the transoms and bolted to the uprights.

The towers are placed on a wooden platform laid on the ground to serve as a foundation.

The tower supporting the mast is connected to the other two by trussed beams, constructed as follows:—Two booms of balk timber are placed, the upper ones on the top of the staging being halved at their intersection on the above-mentioned tower, and projecting about 4 feet beyond on either side; the lower booms take their bearing on the first transom from the top. The two booms are connected by iron bolts placed at distances of about 5 feet apart, with cross braces cut between; the remaining side is

connected by a single balk, with two inclined struts if the span be large.

The derrick is anchored by means of chains, which are passed over the sleepers at the top of the staging, and are connected to the platform at the bottom of each tower, which is loaded with bricks, stones, or other material to a weight of at least twice the load to be raised; the chains may be tightened by means of coupling screws.

To prevent the towers and platform racking when the crane is loaded, the towers may be braced on two sides as shown in figure 240, or better still on the three sides either by lashing scaffold poles or bolting square timbers to form braces, or preferably by steel ties. If the towers are very tall, say, above 70 feet, horizontal struts about the towers should be fixed at the level where the braces intersect.

2. In the second method, commonly applied in Scotland, a balk of timber is used in the place of each built-up tower, these having raking shores on all their sides; the arrangement for supporting the platform is similar to that described above, taking care to fasten the sleepers direct on to the uprights.

Lifts.—Lifts similar to those used in mines are often constructed to raise material to the various floor levels of tall buildings of great area. In these it is often convenient to distribute the material by means of tramways on each level as the work proceeds. The trucks are loaded at the base of the building, run on to the lifts, which latter are often constructed to carry up to about six trucks raised to the level, landed on to a staging and diverted by means of turn tables to the direction required. This method is often used where the plan of the building is not convenient for the construction of derrick towers.

Centering.

Definition. — A framework of timber arranged to temporarily support the voussoirs of arches during their construction is termed a centre; they must be constructed sufficiently strong to resist any deforming stresses, and require to be carefully and rigidly put together; but as they are only for temporary work, care should be taken to frame them so as to do the timber the least amount of injury. Centres consist of ribs supporting a curved surface made to the outline of the soffit of the intended arch, together with braces and ties arranged to prevent the least appreciable deformation.

Classification.—Centres are classified under two heads: (*a*) those with built-up ribs; (*b*) those with solid ribs. The first are used for spans up to about 20 feet, the second for spans above that dimension.

Ribs.—There are two methods of building the ribs: (*a*) By short pieces of boarding about 1 inch thick cut to the required curve, having the joints of the same normal to the curve; the rib is made in two thicknesses nailed together, with the pieces overlapping, as shown in figure 241; (*b*) ribs are made in one thickness in the larger centres out of timber from about 3 inches thick and upwards, the pieces being connected together by dogs or preferably by iron plates screwed over the joint, as shown in figures 244 and 247. This centre is designed to be supported at two intermediate points in addition to the extremities to prevent deformation during the building.

Ties. — The ribs are secured at their extremities, to prevent them spreading, by pieces of timber being spiked or bolted to them, as shown in figures 241 and 246.

Braces.—These are required to support the ribs at intervals to prevent any deformation in the curve; they must be

capable of withstanding alternately compressile and tensile stresses, as may be understood if the change of stress upon a centre is noted. Let a centre be complete and in position, and the arch commenced as is usual at both sides, these being carried up simultaneously till they meet in the centre. There is practically no stress transmitted to the centre till the angle of the bed joints exceeds the angle of repose of the material of which the voussoirs are composed, but when this is passed there is a compressive stress exerted at the haunches tending to make that part sink and the crown to rise; this stress is so great in the large centres that it becomes necessary to weight the crown while the haunches are being built. When the arch is nearly completed, that is, just before the keystone is inserted, the stresses are reversed, a compressive stress being exerted on the braces at the crown and a tensional stress on those at the haunches. Figures 241 to 244 show the usual methods of securing the ends of the braces.

Laggings.—Strips of wood are nailed to the ribs to form the surface to support voussoirs called lagging pieces; these vary in size according to the weight to be carried and the distance the ribs are placed apart, from $1\frac{1}{2}$ in. × 1 in. in the smaller centres to about 4 in. × 4 in. in the larger types.

The laggings for rough brick or stone arches are usually placed a short distance apart, but for gauged brick arches they are fitted and placed close together, the joints being cleaned off and the curve made true with the plane, in order that the position of each voussoir may be marked thereon. The surface may also be formed by two layers of 11 in. × $\frac{3}{8}$ in. pine, bent about the curve and fixed to the rib, as shown in figure 241.

Centres for stone arches where the voussoirs are large have no laggings, but the ribs directly support the voussoirs;

Fig. 243.

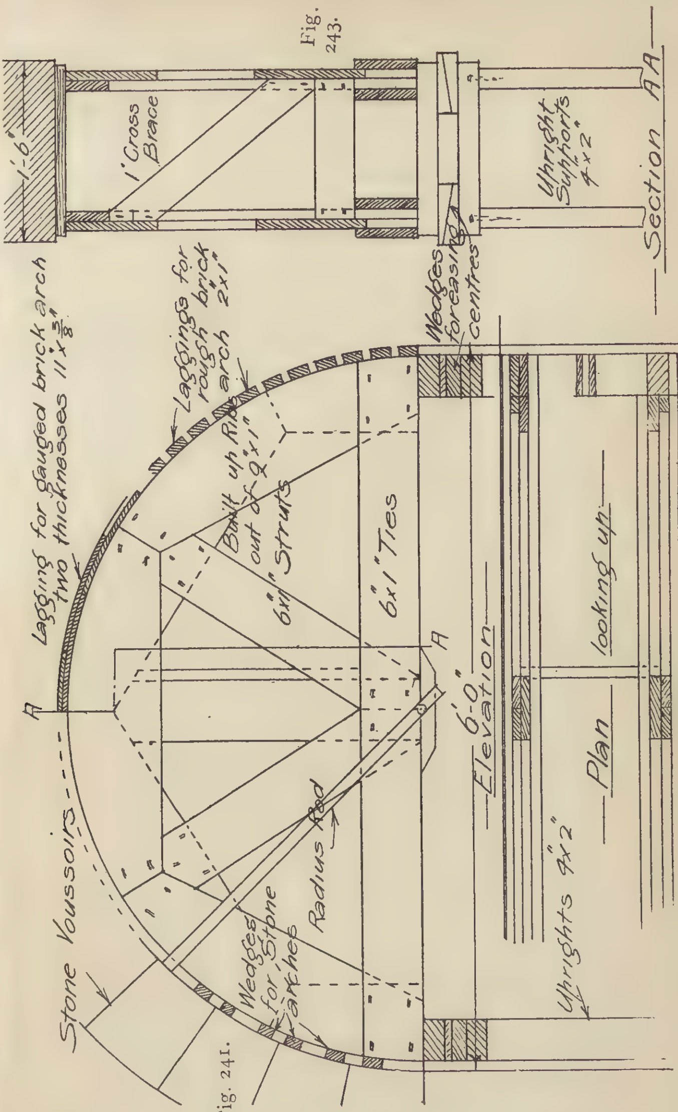


Fig. 242.

Fig. 241.

they are gauged for their correct position by means of a radius rod, and are packed up by means of wedges, as shown in figure 241.

Figures 244 to 248 show a centre and details suitable for spans from 25 feet to 40 feet. In this the rib is built up of solid members, as shown in the details. This centre is an economical construction where the space beneath the arch is not required during construction. Figures 249 to 252 show a form of centre much used where the space beneath the arch is required for traffic during its construction. This centre is supported at the sides only, and the main tie has been raised considerably in order to give greater headroom. Such centres as these are suitable for the construction of bridges; the ribs are usually placed about 4 feet apart and the laggings are out of stuff about 5 in. × 3 in., and a pair of wedges is placed under the feet of each rib.

Supporting and Easing of Centres.—Provision must be made for the gradual easing of centres, in order to allow the arch to take its bearing gradually; this may be accomplished by means of lifting jacks or wedges, the latter being usually adopted, the arrangement being as follows:—The ribs are fixed to a plate, extending the length of the centre; these rest upon pairs of folding wedges, which in their turn are supported by similar horizontal plates supported by uprights, which rest with their lower end on the ground or other solid support. The folding wedges between the horizontal plates are greased if the centres be heavy, and are for the purpose of easing the centre gradually; these are shown in figure 248.

Steel Centres.—For very large arches the ribs of the centres are now frequently constructed of rolled steel joists bent to the required curve, and trussed beneath to meet the requirements of the case. They are supported at their extremities on screw jacks for easing on completion.

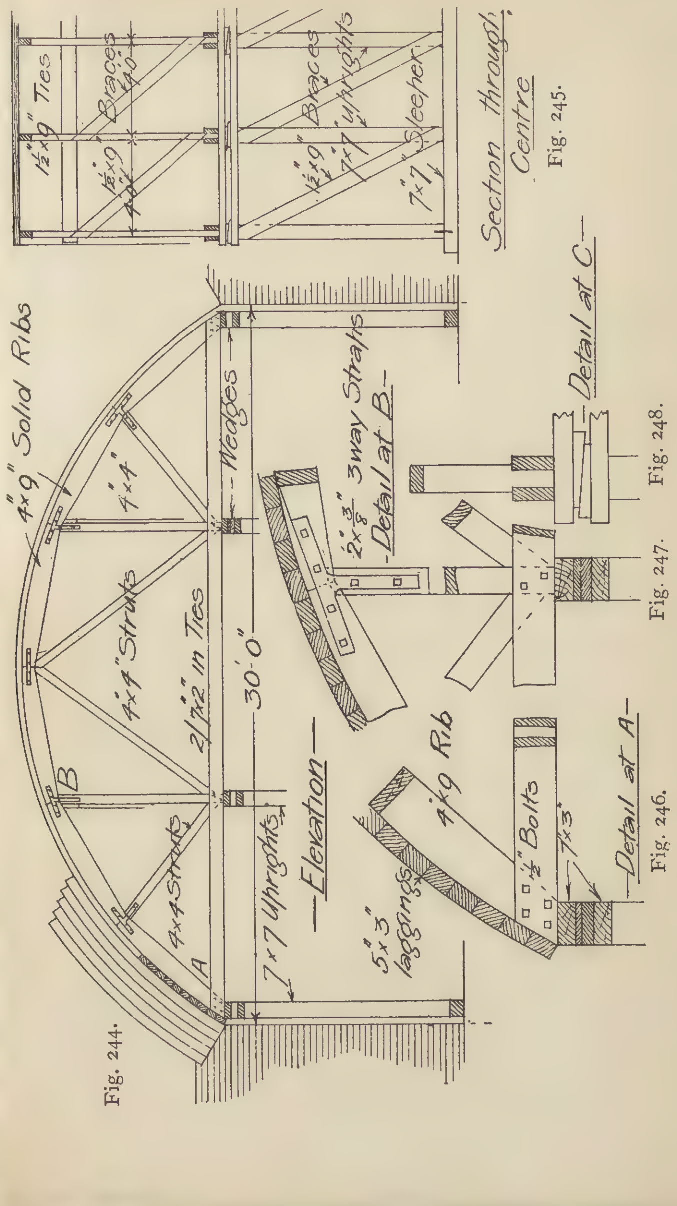


Fig. 244.

Fig. 245.

Fig. 246.

Fig. 247.

Fig. 248.

Centres for Intersecting Arches.—The centres for barrel-headed vaults are arranged at their intersection with other vaults as follows:—The centre for the main vault is made in the usual manner, the distance between the ribs varying with the weight to be carried, the whole of the ribs being covered with the laggings. The centre extends beyond the line of intersection of the side vaults at each side, and is fixed into position. The centre for the side vault is now constructed, one rib being placed in contact with the main centre at the springing points, the others at the requisite distance apart; the laggings are then laid on, extending in each case past the end rib till they touch the surface of the main centre, to which they are scribed and fixed. Should the distance between the end rib and the surface of main centre exceed the distance between the ribs, a backing piece is fixed to the main centre to support the laggings.

Groined Vaulting.—The centres for groined vaulting are made in two ways, depending upon the construction of the vault. If the bed joints and courses of the vault be laid horizontally the centres are constructed as above described, provision being made at the intersections for the groin-stones projecting below the surface of the vaults; but as in the case with many pointed intersecting arches, where the panels form part of a domical or an ellipsoidal surface, ribs to support the groins only are made, the ribs being rebated along their upper edges to receive the stone panels, and built first. As each course in the panels is similar to a portion of a bed course of a dome, each course only requires supporting when the bed joints exceed the angle of repose of the material, and then only till each course is complete, or takes its abutments, as in this case, against the groined ribs. The support for this work usually consists of a curved wood rule held in position.

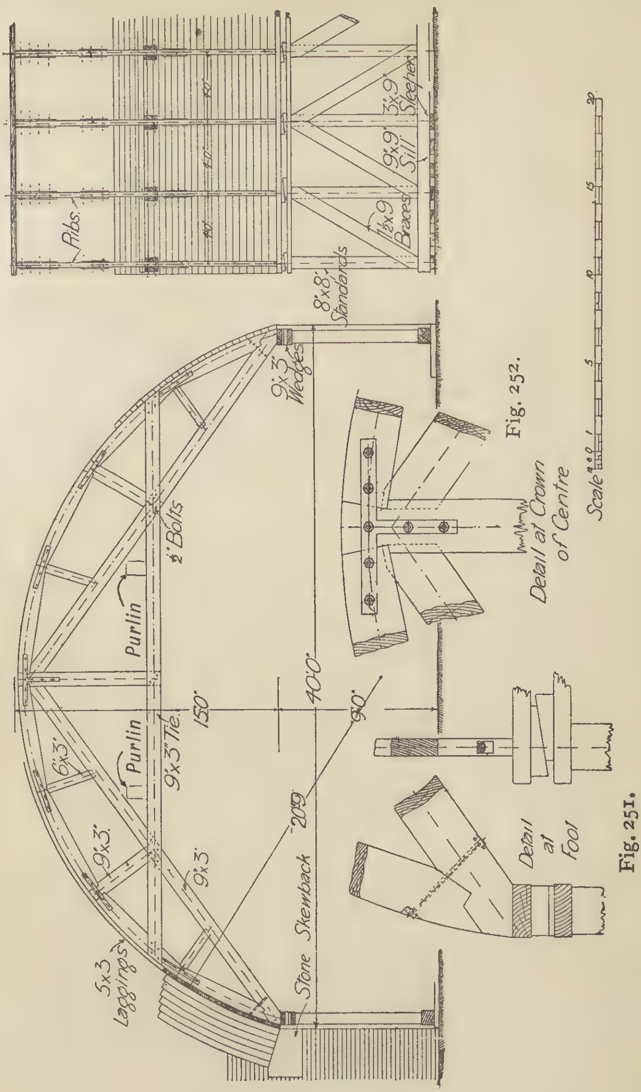


Fig. 249.

Fig. 250.

Fig. 251.

Fig. 252.

Shoring.

Definition.—Shoring is the art of temporarily supporting structures that are in an unsafe condition till such time as they have been made stable, or in supporting walls, the lower part of which has been removed to allow of a large opening to be made and which is to be spanned by an arch or girder, till the construction or fixing of the latter has been completed.

Object of Shoring.—The object of shoring is to prevent dangerous walls developing and continuing symptoms of failure, and to retain the unstable position till they can be more permanently secured. Shores would only be used in exceptional instances to straighten walls.

Theory of Shoring.—Walls when shored may be considered to be acted upon by the following forces:—viz., vertical, horizontal, and inclined, thrusts of floors, roofs, shores, or other forces; and to attain equilibrium it is useful to know the greatest disturbing force due to the thrust of roofs, floors, etc.; to determine the necessary shores to equilibrate and counteract the disturbing force, as any intended equilibrating force greater than the disturbing force has the tendency to act detrimentally to the stability of the wall. This may be determined by the principle of moments.

In practice it is impossible to determine the amount of the actual disturbing thrust tending to overturn the wall, but the maximum value of the overturning thrust capable of being resisted by the wall can be determined and provided for.

Classification.—There are three general systems of shoring, known as—(1) raking, (2) horizontal or flying shores, (3) dead or vertical shores.

(1) *Raking Shores.*—These consist of pieces of timber placed in an inclined position with one end resting against

the faces of defective walls, the other upon the ground, the most convenient and best angle for practical purposes being 60°, from which they vary to 75°; the angle is often determined in urban districts by the width of the footway.

These shores are fixed in systems of one or more timbers placed in the same vertical plane inclined at different angles, and supporting the building at varying levels.

The horizontal distance between the systems in dead or unperforated walls is usually not more than 8 feet; but on walls pierced with windows they are placed on the intervening piers.

A wall-plate, consisting of a 9 in. × 2 in. or 9 in. × 3 in. deal is placed on the wall to receive the ends of the shores, being fixed to the wall by means of wall hooks driven in the joints of the brickwork. The wall plates should be in one piece throughout the system; if owing to their length it is necessary to have them in two pieces they should be halved and securely spiked as shown in figure 256. To form an abutment for the end of the shores, needles, consisting of pieces of 4 in. × 3 in., cut as shown in figure 254, are passed through a mortice made in the wall-plate, and projecting in the wall at least 4½ inches, a half-brick being taken out to receive them. The following considerations determine the position of the needles:—The end of a raking shore should only be placed where there is something such as a floor or roof at back of wall to resist the thrust, otherwise the walls are liable to bulge inwards at that part; there is also a danger near the top of the wall of that part being pushed off if it be not sufficiently heavy. The centre line of shores should, therefore, be made to point directly below the wall-plates if they should be on the wall in question; but if the joists should be parallel to the wall, the centre lines of the floor, wall, and shore should meet in a point. The needle should be placed so that the pressure exerted by it takes place along

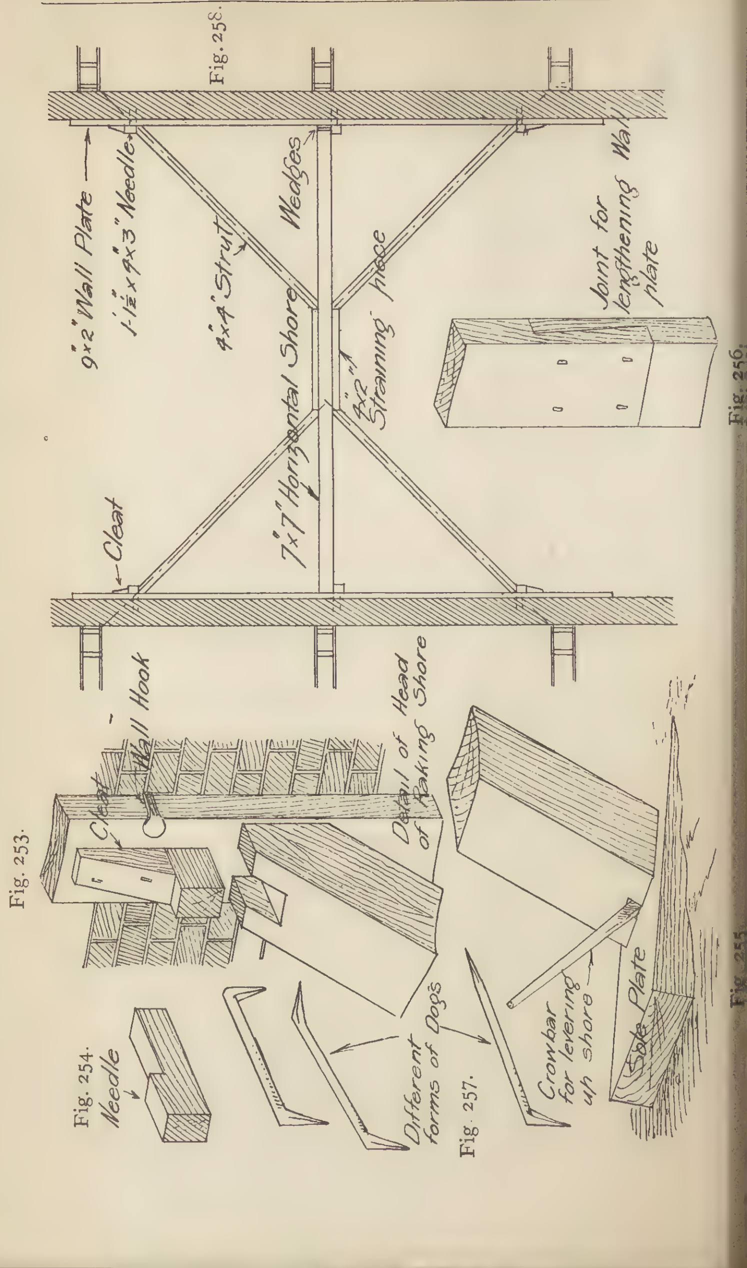


Fig. 258.

Fig. 256.

Fig. 253.

Fig. 254.

Fig. 257.

Fig. 255.

the centre line of the shore. The shore should be notched out at its upper end to receive the needle, thus obviating any tendency to lateral motion. The needle is also further supported at its top side by a cleat nailed on the wall-plate, as shown in figure 253.

Sole Piece.—The feet of the shore rest upon a sole plate usually embedded in the ground in an inclined position, and consisting of a piece of 11 in. × 3 in. The inclination of the sole plate must not be at right angles to the shore, the rule in practice being to fix it 1 in 24 out of the perpendicular to the shore to enable the latter to be tightened up gradually by means of the crowbar. On soft ground the sole plate is bedded on a platform of timber to distribute the pressure over a greater area. The shores are tightened up by means of a crowbar inserted in a slot made in the foot of the shore, as shown in figure 255; wedging should not be resorted to here, as the vibration caused would be detrimental to the already unstable building; the shore should only be forced tight, but not enough to disturb the wall.

When the shore is in position it is secured to the sole piece by an iron dog, and a cleat is nailed on the sole piece in front of the shore. Where more than one shore is used in a system, the bottom ends are bound together either by hoop iron or pieces of boarding nailed across the whole of them on each side to connect them all at this part. At intervals in the height, boards are nailed to the sides of the shores and the wall-plate—these are called struts; they have the effect of binding the whole of the pieces together, and of stiffening the shores considerably, as shown in figure 259.

Maximum Overturning Thrust.—If the strength of mortar joints is neglected, which it is wise and safe to do, for the calculation of the strength, the moment of the greatest

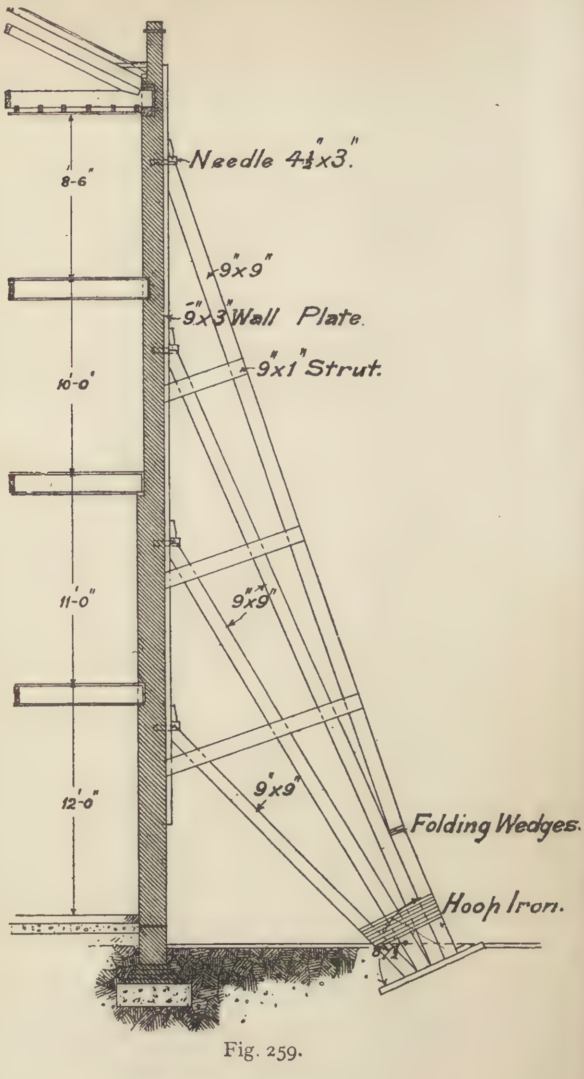

Needle 4½"x3."
8'-6"
9"x9"
9"x3"Wall Plate.
9"x1"Strut.
10'-0'
11'-0"
9"x9"
12'-0"
9"x9"
Folding Wedges.
Hoop Iron.

Fig. 259.

overturning thrust, if the wall is on the point of overturning, cannot exceed the moment of the stability of the wall, and if Q represents the disturbing force, and W_1 the weight of the wall above the point of application or the upper portion of the wall which has the tendency to be lifted on the tightening of the shore acting at its centre of gravity, as shown in figure 260, then—

$$\left.\begin{array}{c}\text{Maximum overturning}\\ \text{moment}\end{array}\right\} = \left\{\begin{array}{l}\text{Maximum moment of}\\ \quad\text{stability}\end{array}\right.$$

$$\left.\begin{array}{l}Q \times \text{perpendicular distance to}\\ \quad\text{point of overturning}\end{array}\right\} = \left\{\begin{array}{l}\text{Weight of wall multiplied by}\\ \quad\text{perpendicular distance to}\\ \quad\text{point of overturning,}\end{array}\right.$$

that is (using diagram)

$$(a)\ Q \times BC \quad = \quad W_1 \times DC$$

In practice the determination of the overturning thrust must be made by inspection and calculation; but the maximum value for any direction is known, because its moment cannot exceed the value of the maximum moment of stability, that is, $W_1 \times DC$.

Equilibriant Force.—The action of a shore is two-fold, it tends to equilibrate an overturning wall by the moment of its weight, let this be called R; and by the moment of its thrust, which thrust may be of any value up to the ultimate compressive strength of the shore, the intensity of the thrust being created by the levering up of the shore. For any given shore the first factor is determinate, and, using the diagram, the value of R is $W_2 \times KC$ when W_2 is the weight of the shore, and tends to counteract the moment of the overturning force Q; the value of the overturning thrust is now, therefore, the moment of $Q - R$ divided by the perpendicular distance from Q to the overturning point,

$$\frac{(Q \times BC) - R}{BC}$$

that is, $AF = \dfrac{(Q \times BC) - R}{BC}$, let this be called S.

The value of R is the perpendicular component of the reaction of the ground due to the weight of the shore, at the foot of the shore multiplied by its distance from C, minus the weight of the shore acting at its centre of gravity into its distance from C; the algebraical value of this will equal in a shore the centre of gravity of which is in the centre of

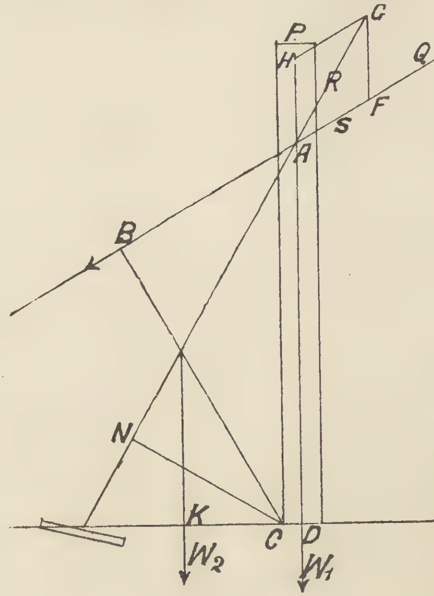


Fig. 260.

its length $W_2 \times KC$ as already stated, and in a direction opposite to the overturning force Q.

The second factor of the shore, viz., its thrust, cannot exceed the resultant of the overturning force S and the weight of the wall above A, the direction of the vertical component and resultant force being known, which latter must not be less than the value of AH obtained by completing the parallelogram. Let AF = the force S and AP

the direction of the wall, above A; then the thrust of the shore, or the amount it is in compression, is determined by completing the parallelogram FGHA, and to preserve equilibrium cannot exceed the value of AG, which may be easily determined graphically.

The equation may be mathematically stated thus (using the diagram):—

$$(b) \quad (W_2 \times KC) + (AG \times NC) + (W_1 \times DC) = Q \times BC$$

The value of W_1 is AH, and may be stated in terms of AG, and Q may be obtained from equation (*a*). W_2 may be obtained by calculating the weight of the given shore, the distances KC, NC, DC, and BC may be obtained from the diagram, thus leaving only AG unknown, which may be easily determined by the equation. Q.E.D.

Section of Shores.—The value of AG is the amount of stress the shore is compressed, and the required section may be obtained from the formula for compression—

$$P = \frac{sf}{1 + a\frac{l^2}{r^2}}$$

as stated in the chapter on Pillars; but it is usual to use rectangular sections much in excess of the required dimensions for compression, as larger timbers can be converted more economically into smaller scantlings for subsequent use.

(2) *Horizontal or Flying Shores.*—These are used mostly in urban districts, usually where one of a number of terrace houses has to be removed, to temporarily support the houses on either side; they are erected as the old house is being removed, and are taken down when the new building is of a sufficient height to dispense with them.

They consist, as shown in figure 258, of a timber

placed horizontally, and cut tightly between the walls to be supported, the ends resting against wall-plates placed vertically on the walls, the method of fixing being as follows:—

Two wall-plates are fixed, one on each wall in a similar manner to those described, having a needle fixed where it is desired to place the horizontal timber, care being taken to keep this as far as possible in the line of the floors on either side. The horizontal shore is now placed in position, having a straining beam out of about 4 in. × 2 in. nailed on the upper and lower sides. This timber rests upon the needles, and if there is any space between the end of the shore and wall-plate, a pair of folding wedges is inserted and driven up tightly.

The struts are now fixed, a pair at each end; these are usually out of 4 in. × 4 in., and placed at an angle of 45° they rest with one end on the shore, butting against the straining beam, and with their other end resting against the wall-plate, and butting against a cleat nailed on at that part. The cleats should be housed in to the wall-plate about ¾ inch, to prevent them being pushed out of their position by the thrust down the strut. When this method is employed the struts have to be tightened by wedging as follows:—The struts are all cut in, with a pair of folding wedges inserted and driven between the straining piece and struts on the upper side of shore, causing it to deflect slightly, thus tightening the whole. The inclined struts serve to stiffen the horizontal shore, and also to support the wall at their other extremities.

(3) *Vertical or Dead Shores.*—This is the method of temporarily supporting the upper parts of walls, while the lower parts are removed to renew defective foundations, or to make large openings in the walls. Let the lower part of a dwelling-house be required to be taken out and

converted into a shop-front, the method of procedure would be as follows :—

The whole of the floors and roofs, and all loads bearing

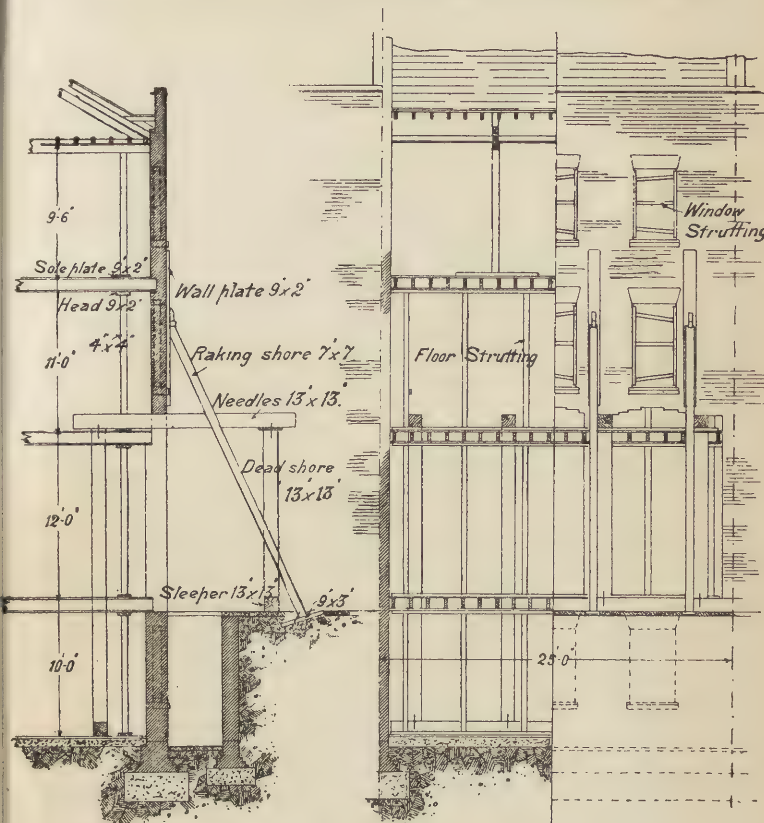


Fig. 261. Fig. 262.

on the wall to be operated on, are supported by a system of strutting from the roof to the solid ground under basement floor ; this relieves the wall of all but its own weight.

Perforations are now made in the wall a short distance

above the line of the top of the arch or girder that is to finally support the wall. Through the holes needles are inserted, consisting of balk timbers; these should not be placed a greater distance than 6 feet apart in brick walls, as shown in figures 261 and 262.

The needles are supported by upright members, called dead shores, consisting also of balk timber, one on each side of the wall; these must be continued down to the solid ground; those on the outside must not rest on the crown of any vaults, but must be either taken right through, or else the crown of the vault must be strutted up from below in a direct line with the dead shore above.

There is often a difficulty in getting in the dead shore on the inside in one piece; where this is the case, the lower halves are placed in first, a transom being placed across the whole of these; the upper shores are then placed on the transom directly over the lower members and under the needle at its upper end. Between the needle and the dead shores a pair of oak folding wedges of the same width as the dead shore are inserted, which, on being driven home, force the needle tightly against the underside of the brick-work. The lower ends of the inside and outside shores should rest upon sleepers, which serve to distribute the weight over a greater area, and also as a fixing for the lower ends of shores. The shores when in position are well dogged to both the needles and sleepers.

Before any of the piers are removed, all the window openings must be strutted apart, as shown in figure 262, to prevent any deformation taking place. In ordinary small windows this consists of an upright against each reveal, with about three struts between; but in the larger openings the arches require to be supported by a turning piece, or centre, made to fit, with the reveals strutted as before.

If the building be old or at all defective, raking shores are imperative, but it is wise under all conditions to use

them to steady the building during the progress of the works. These are fixed against the piers between the windows and close beside the dead shores.

Having the shores all fixed in position, the two end piers should now be built, or if the supports are to be stanchions these should be erected to receive girder, the minimum amount of the old wall being taken away to allow for this work. The intermediate piers or wall may now be removed. If an arch is to be used it should be built and the spandrel filled in to the underside of the old brickwork, or if a girder be employed it should be raised and fixed, the cover-stones bedded, and the brickwork filled in to the underside of the old work; this new brickwork should all be built in cement mortar to avoid any settlement in the new work.

A week at least should be allowed for the new work to set before any of the shoring is struck. The needles should be removed first, then the strutting from the windows, the strutting under the floors inside, and, lastly, the raking shores. About two days should be allowed between each of these operations in order that the work may take its bearings gradually on the new supports.

Great care is required in carrying out these operations in a corner house; the needling would be made to suit the special requirements of the case, but under all conditions the angle of the building should be shored with raking or horizontal shores if that be more convenient.

CHAPTER VI.

HALF-TIMBERED WORK.

Definition.—Buildings with walls constructed of a framework of timber, consisting of a number of uprights, heads, sills, and transoms, as shown in perspective, figure 263, and

Fig. 263.

in section and front elevation, figures 264 and 265, the intervening spaces or panels being filled up with brickwork, stonework, or tile hung, are known as half-timbered work.

Object.—The aim of this class of construction at the present day is to obtain a picturesque effect in thin walls having the rigidity of wood framing, and partially possessing

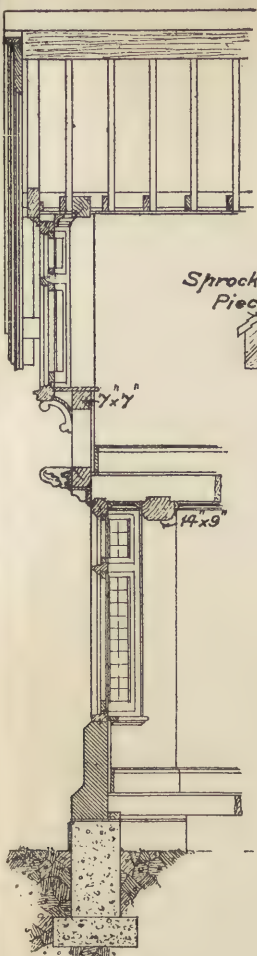


Fig. 264.

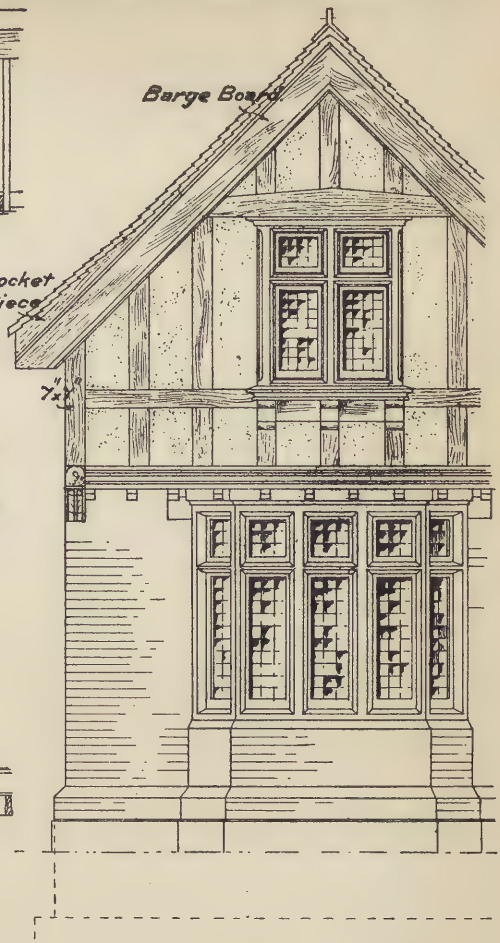


Fig. 265.

the fire and weather-resisting properties of brick and stone-work. This method at the present is much limited by the Model Bye-Laws.

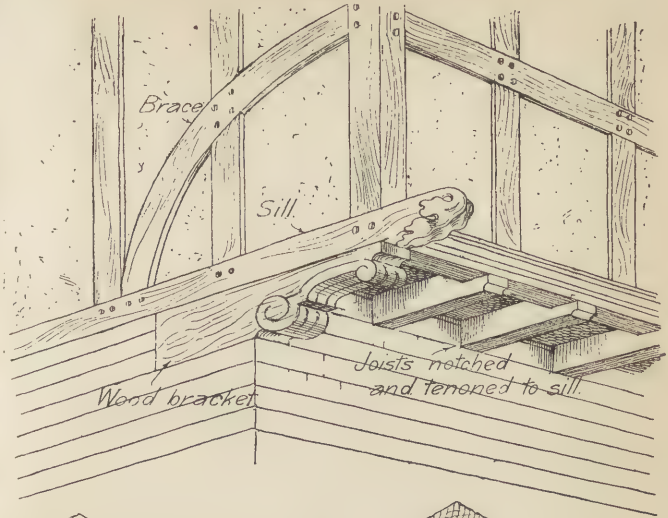
Foundation.—The foundations in all soils but dry gravel or rock soils, which may be built upon direct, should consist of beds of concrete in width and depth proportioned to the bearing strength of the soil with the load carried. The walls should then be carried up in brick or stone to the underside of the ground floor, at which level there should be an efficient damp-proof course; on this may be bedded the wooden sill, but it is better if the brickwork is carried up to the first floor level, or at least to the ground floor window sill.

Wood Framework.—The sill is first bedded in mortar upon the brickwork, being bevelled halved at all angles, as shown in figure 267. The head is prepared (as shown in figure 267) at the same time as the sill. These two members are framed together in a similar manner, and are made through or continuous members, the next in order being the angle posts, which are tenoned at ends to the sill and the head, and mortised to receive the more important intermediate horizontal members, viz., those which usually carry the line of the window sills and heads, as shown in figure 268, thus reducing the number of short horizontal members, and adding to the rigidity of the framing.

Door and window posts are tenoned at their feet and heads into these members, as shown in figure 268, and the minor horizontal members are framed between the angle, door, and window posts; and, lastly, the intervening uprights or studs are tenoned into the horizontal members. The parts should be formed of stuff not less than 6 in. × 6 in., and are connected by the mortice and tenon joint, draw-bored and pinned. The pins or trenails should be made of oak; iron nails are not good, as they rust and perish.

Braces.—Angle posts are often further secured by braces, which are framed and pinned into the plates and uprights. Curved pieces of timber are frequently selected for these

Fig. 266.



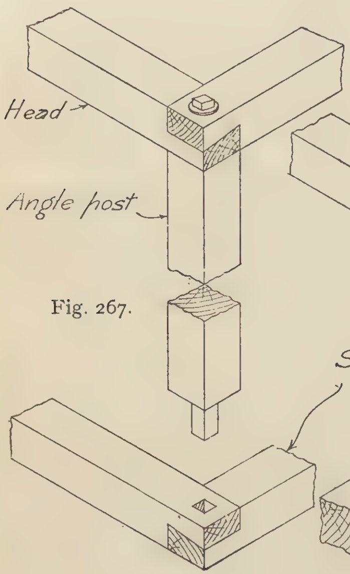


Fig. 267.

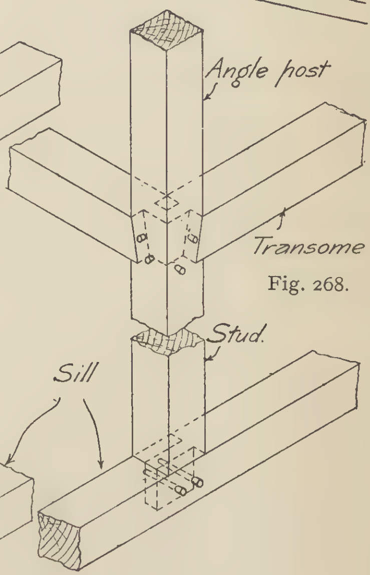


Fig. 268.

members, to enable them to be tenoned square, or nearly so, into the post and sill, the tenon being much stronger than if placed in an inclined direction; and when the intervening spaces are filled in with brickwork they are nearly as strong as straight braces, and have a more picturesque appearance, as shown in figures 266 and 275. If there be more than one window at the same level, it is usual to fix a pair of braces between them, as shown in figure 274. Where braces cross they should be halved at the junction, care being taken not to let one run through and the other cut over it, as these members may alternately be in tension and compression.

Figures 269 to 274 show six methods of arranging braces to stiffen the timbering, and these generally should be tenoned and secured by oak pins.

Material.—Oak should be employed for outside work of this description, the front faces of which are often stained a dark brown colour, and varnished or tarred all over; but they are frequently wrought and fixed, and in this condition they weather very well. If pine is used it should be tarred on all its covered faces to render it more durable, and the wrought face painted.

Flooring.—The ground floors are often paved with bricks laid on edge diagonally, or to a herring-bone pattern, or with tiles or stone flagging. Wherever this method is adopted, a layer of concrete, at least 6 inches thick, must be laid before bedding the bricks, tiles, or flagging, to prevent the damp or the ground air rising. These are good and sanitary for kitchens and sculleries, but for living and bedrooms, when on the ground floor, wood floors should be used. Wood block floors are best adapted for this position.

The joists in the upper floors often run over the head of the framing or wall of the lower storey, and project abcut

Fig. 269.

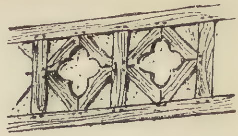


Fig. 270.

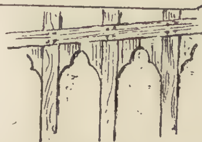


Fig 271.

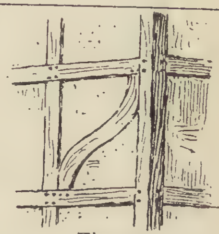


Fig. 272.

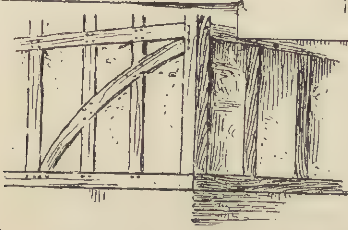


Fig. 273.

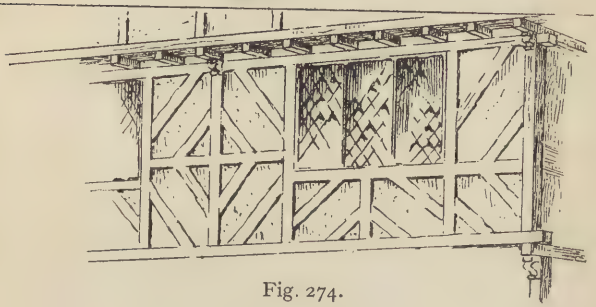


Fig. 274.

Figs. 269 to 274.

1 foot 6 inches, the sill of the upper storey being fixed to the ends of the joists, and the framework of the upper front being carried up at this projection, as shown in figures 266 and 275. The ends of the joists are usually cut to some ornamental pattern, and are supported where they come over the principal upright members by brackets, or by solid carved or moulded wood cantilevers.

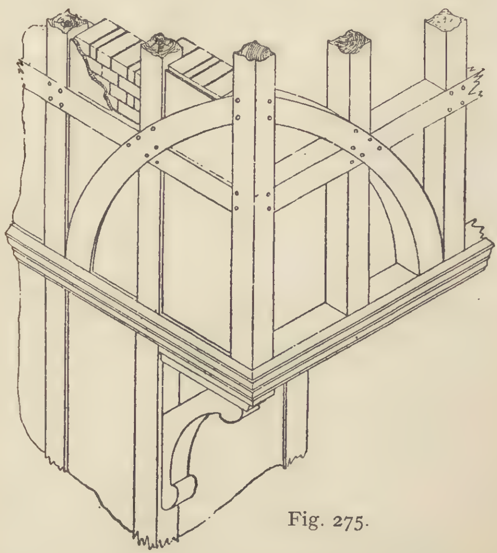


Fig. 275.

Exterior Wall Coverings—Rough Cast.—Buildings with walls of this type originally prevailed in those districts in which wood was plentiful, and where stone or bricks were either scarce or expensive. In the earlier examples the panelling was filled in with wicker-work or lathing, which was covered in stucco in two coats, the first coat usually containing hair; before the second coat was set a mixture of well-washed sand, fine gravel, and pure hot lime, in a semi-fluid state, was thrown on, forming what is known as

rough cast, this being very effective for weathering purposes. Sometimes the coats were fixed over the face of the timber, and sometimes set back from the face to present a panelled appearance on the exterior. Where the panels are filled with brickwork, the latter are often covered with rough cast, as shown in figure 275.

Tile Hung.—The exterior surfaces of buildings of this description are often covered with plain tiles, as shown in figure 276, which are fixed as follows:—Battens similar to roofing battens, about $1\frac{1}{2}$ inches wide and $\frac{3}{4}$ inch thick out of oak, are fixed to the studs by nailing. Fir battens in this position are unsuitable, as they split very readily when nails are driven into them. On these tiles are hung by nibs projecting from their upper edges, and fixed by being nailed to the battens; special tiles are made for covering the internal and external angles, as shown in figure 276. This method is often adopted for thin brick walls for effect, the prevention of dampness, and to preserve the equability of the temperature.

Brick and Stone Filling.—Panelling is frequently filled in with brick or stonework, which should be of a thickness sufficient to prevent dampness driving through, but if the brickwork is of half brick only in thickness it should be covered with rough cast or with tiles. The bricks are often laid diagonally, or to a herring-bone pattern, or other design.

Internal Wall Coverings.—The internal wall surfaces are usually either boarded or plastered. The latter is the more sanitary, especially if the spaces between the studs are filled in with brickwork, and the plaster is laid on the surface direct; but where boarding is employed, the hollow spaces behind form a harbourage for vermin.

Roofs.—The roofs in these buildings are usually steeply pitched, varying from 45° as the minimum to 60° as the maximum. Where the spans are large enough to be trussed, the collar-beam is the type generally used, as it lends itself more favourably for the formation of attic rooms than any other kind. The ceilings are supported by ceiling joists, nailed at the required height to every pair of common

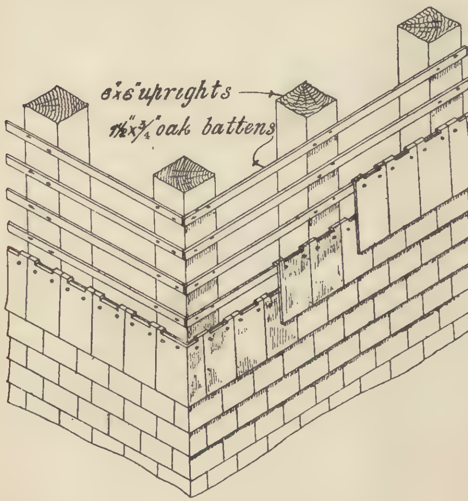


Fig. 276.

rafters. The feet of the common rafters are fixed to the head of the wall framing, beyond which they project to form the eaves ; but where the rooms are constructed entirely in the roof, the common rafters are fixed to the floor joists direct, or are cut on to a plate fixed to them, thus preventing any inclined thrusts on the walls.

Ashlaring.—Rafters fixed as just described enclose a triangular space, the angles of which, next to the floor, cannot very advantageously be used. To avoid this, short uprights of a length not less than 2 feet are fixed vertically,

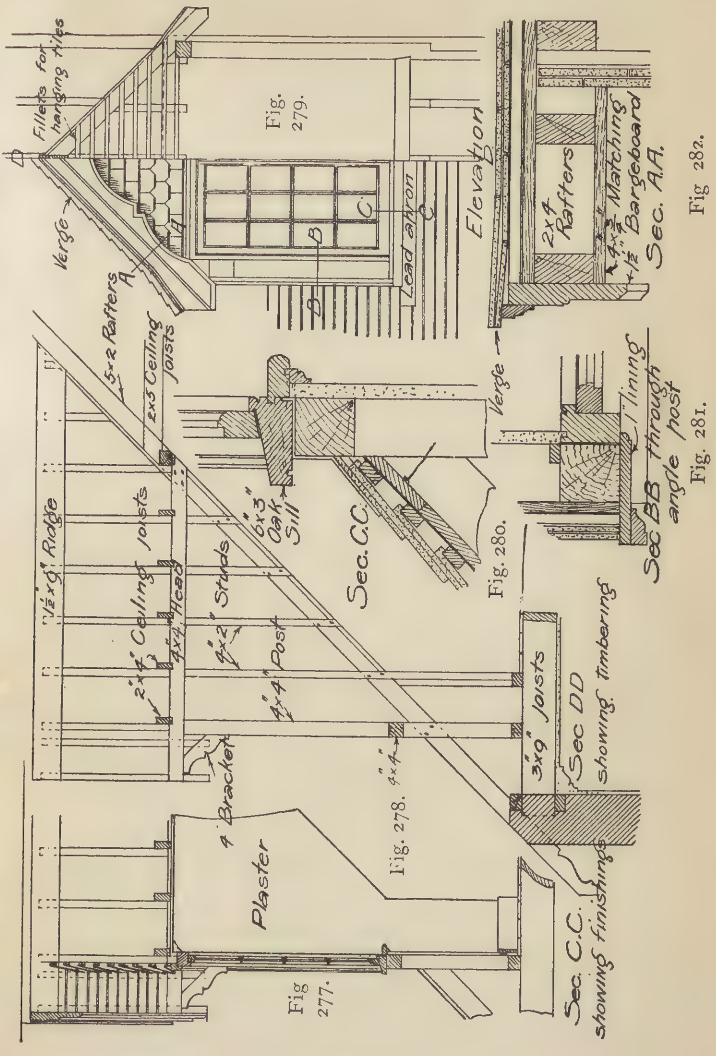


Fig. 279.

Fig. 282.

Fig. 281.

Fig. 280.

Fig. 278.

Fig 277.

cutting off these acute angles, as shown in figure 688 *Elementary Course*, by being tenoned into a floor plate, cut against and spiked to rafters or halved and nailed to the common rafter and floor joists. These are plastered over and are known as ashlaring.

Dormers.—Attic rooms are usually lighted either by sashes placed in the gables or by dormers. The construction of a dormer is shown in figures 277 to 282. The roofs are usually constructed at ends as gables, the hipped ends being a later arrangement, and it is to the treatment of the gables and the intersections of the dormers and subordinate roofs principally that these buildings owe their quaint picturesque effect.

Barge-boards.—The roofs at the gable ends usually project about 1 foot beyond the face of the wall, the rough timbers being covered by a lining called a barge-board, as shown in figure 282. This is fixed on to the face of the last rafter, and is sometimes highly ornamented with carving or moulding; if very wide, it should be framed. The roof tiles should project 1 inch beyond the face of the barge-board, the tiles along the verge or the exposed edge, as shown in figure 279, being bedded in mortar and neatly pointed. Where the face of the dormer or gable is tile hung the space between the barge-board and the tiles should be match-boarded, the matching being scribed to the tiles, as shown in figure 282.

The barge-boards in the larger roofs are usually framed into an upright post for greater strength, the upright projecting above the roof and below the barge-board, the free ends being turned and carved. This member is termed a "finial."

Eaves.—The rafters at their lower ends project beyond the face of the wall at least 1 foot, so as to throw all rain-water clear of walls. The projecting part is called the "eaves."

The eaves are treated in either of the following ways:—(1) By the ends of the rafters being cut to some ornamental pattern, the wall being built up close to the underside of the roof covering; or (2) by forming a flat soffit by nailing bearers one end to the ends of the rafters, the other resting on the wall, or by shaping the bearers so as to form a cove, the soffit being lathed and plastered.

The rain from the roofs is collected by means of cast-iron gutters screwed on to the ends of the rafters, or supported on brackets screwed on to the side of the rafters; in rural districts, where water is scarce, the water being conveyed by down pipes to a reservoir prepared for that purpose.

Sashes.—Casement sashes are most suitable for this class of work. The solid sash frames are fitted in openings formed in the rough timber framing, and usually stand back about 2 inches from the face of the latter. A small moulding is mitred, and fixed at the sides and head of frame to make good the joint. This moulding should be tongued to the rough framing to avoid any through joint. The sill of the sash frame should be bedded in white lead, and be grooved to fit over an iron water bar that has been let into the sill of the rough frame; the part of the latter projecting beyond the sash frame should be weathered. The casements are often made of iron with small rectangular or diamond-shaped leaded lights, as shown in figures 265 and 274.

Chimneys.—In these structures, where so much timber is used, great care must be taken in building the chimneys to keep the brick or stonework about the flue walls of a sufficient thickness to avoid danger from fire. They should be kept at least 9 inches thick, unless they are rendered in Portland cement; they should be carried at least 3 feet above their line of junction with roof, as shown in figures 128 and 129, and in any case the top of chimney shaft must be above the highest ridge to prevent down draughts. The shaft

should be carried as much as possible above the height stated as is consistent with stability, to increase the up-draught.

The Model Bye-Laws which apply to urban districts state that the external walls of buildings may be erected of timber framing, provided the new building is distant not less than 15 feet from any adjoining building not being in the same curtilage, and in accordance with the following regulations:—

1. The timber framing shall be properly put together, and the spaces between the timbers shall be filled in completely with brickwork.

2. (*a*) A thickness of at least $4\frac{1}{2}$ inches of brickwork shall be placed at the back of every portion of timber, and shall be properly bonded to the brickwork filling the spaces between the timbers; and

(*b*) Where a new building forms, or is intended to form, part of a block of new buildings which shall be intended for use as dwelling-houses, and shall not exceed three in number, and each of which shall be distant not less than 15 feet from any adjoining building not being in the same curtilage and not forming part of the same block, the persons erecting such new building may construct its external walls of timber framing subject to compliance with the following conditions: that is to say—

(1) The several buildings shall be separated by party walls, each of which shall be constructed in accordance with the requirements of the bye-laws in that behalf, and shall project at least 1 inch in front of any timber framing in any adjoining external wall.

(2) The timber framing shall be properly put together, and the spaces between the timbers shall be filled in completely with brickwork.

(3) The thickness of at least $4\frac{1}{2}$ inches of brickwork shall be placed at the back of every portion of timber, and shall be properly bonded to the brickwork filling the spaces between the timbers.

CHAPTER VII.

PILLARS.

Definition.—Members designed to support loads, and subjected to longitudinal compression, are called pillars or struts; if the material be timber, and in a vertical position, they are particularly known as posts; if of iron or steel, and their axes are disposed (*a*) in an inclined direction, are more generally termed struts; (*b*) in a vertical position, are known as pillars or stanchions; if the section be circular, columns.

Object.—The object of pillars is to carry heavy loads with the minimum sectional area of material. They are extensively used in iron producing countries to support roofs over railway platforms, galleries of public buildings, girders carrying the superstructure above shops, and in those modern erections the framework of which is of steel. These latter are usually enclosed with brickwork or masonry, the purpose of the latter being to resist fire and atmospheric conditions, and to present a good appearance.

Rankine's Formula.—The following is an explanation of Rankine formula $P = \dfrac{Sf}{1 \times a \dfrac{l^2}{h^2}}$, which is given at length in Rankine's "Applied Mechanics," and Wray's "Instruction on Construction," and is stated as follows:—

The intensity of pressure per unit of sectional

area of a long pillar under a light load equals $p = \frac{\text{total pressure}}{\text{total sectional area}} = \frac{P}{S}$; but if the load be sufficiently great, the additional stress due to bending is to the stress due to the direct pressure in a ratio, which increases as the square of the ratio of the length of the pillar to its least diameter; and the total ultimate intensity of resistance to compression on the concave or compression side, whichever is the weaker, is given by—

$$f = \frac{P}{S} + \frac{P}{S}\, a\, \frac{l^2}{h^2} \qquad (1)$$

$$\text{That is } f = \frac{P}{S}\left(1 + a\,\frac{l^2}{h^2}\right) \qquad (2)$$

$$S f = P\left(1 + a\,\frac{l^2}{h^2}\right) \qquad (3)$$

$$\frac{P}{S} = \frac{f}{1 + a\,\frac{l^2}{h^2}} \qquad (4)$$

$$p = \frac{f}{1 + a\,\frac{l^2}{h^2}} \qquad (5)$$

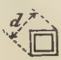
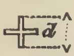
$$P = \frac{S f}{1 + a\,\frac{l^2}{h^2}} \qquad (6)$$

f = intensity of pressure to crush a short column of the material 1 square inch sectional area.
a = constant deduced from experiments on the actual breaking weight of long columns.
h = least transverse dimension, or least dimension of a triangle or rectangle circumscribing the section of the bar.
l = length of bar in same unit as h, the latter usually being taken as the unit.
P = total pressure on pillar.
p = pressure per unit of sectional area.
S = total sectional area.

Experiments have been made upon numerous sections of building materials in ordinary practice to ascertain

the value of a, consequently the application of the formula has been greatly facilitated for many sections, and the formula has been found useful in practice.

The subjoined table is from Wray:—

Nature of Material.	Form of Strut.	Resistance to Crushing. Value of f.		Values of a.		
		In lbs. per sq. in.	In tons per sq. in.	Ends flat or fixed.	Ends round, jointed, or hinged.	One end round, other flat or fixed.
Wrot. Iron	L T + □ ⊔ I	42,560	19	$\frac{1}{900}$		
,, ,,	Hollow Round	39,200	$17\frac{1}{2}$	$\frac{1}{3500}$		
,, ,,	Solid ,,	36,000	16	$\frac{1}{2250}$		
,, ,,	,, Rectangular	38,080	17	$\frac{1}{2500}$		
,, ,,	,, ,,	36,000	16	$\frac{1}{3000}$		
Cast Iron	,, Round	80,000	$35\frac{3}{4}$	$\frac{1}{400}$	Take 4 times value given under "ends flat or fixed."	Take $\frac{16}{9}$ times value given under "ends flat or fixed."
,, ,,	Hollow ,,	,,	,,	$\frac{1}{800}$		
,, ,,	 Square	,,	,,	$\frac{3}{1600}$		
,, ,,		,,	,,	$\frac{3}{800}$		
Mild Steel	Solid Round	67,200	30	$\frac{1}{1400}$		
,, ,,	,, Rectangular	,,	,,	$\frac{1}{2480}$		
Strong Steel	,, Round	112,000	51	$\frac{1}{900}$		
,, ,,	,, Rectangular	,,	51	$\frac{1}{1600}$		
Fir, Dry	,, Round	5,040	$2\frac{1}{4}$	$\frac{1}{190}$		
,, ,,	,, Rectangular	,,	,,	$\frac{1}{250}$		

Fixed and Round Pillars.—Pillars are said to be fixed when the bases are flatly bedded and bolted, and are said to be hinged or rounded when they are free to rotate, as in the case of struts in iron or steel roofs, secured at each end by one bolt.

Working Strength.—It is usual to take one-fifth to one-tenth of the ultimate resistance.

Generally.—The greatest resistance of materials to compression is probably when the ratio of length to least dimension of the transverse section is as 1 to 1; but there is no sensible tendency to give way sideways in granular materials, such as brick or stone blocks, cast-iron pillars and struts, when the length does not exceed five times its least dimension; and in fibrous materials, such as wrought iron, steel, and dry timber, when the length does not exceed ten times its least dimension. Pillars of granular materials, with a length between five and thirty times the least dimension, usually fail partly by crushing and partly by bending; pillars of fibrous materials, the length of which is from ten to sixty times the least dimension, generally fail in a similar manner. When these ratios are exceeded, they should be considered to fail wholly by bending. The variations of the ratio of the length to the least dimension of pillars are generally included between 1 to 5 and 1 to 60.

EXAMPLE: Determine the strength per square inch of section of cast iron hollow column, ends flat or fixed, the length being thirty times the least dimension.

The values of f and a are to be taken from the table given.

CAST IRON.

$$p = \frac{f}{1 + a\frac{l^2}{h^2}}$$

$$p = \frac{80{,}000}{1 + \frac{1}{800}\frac{30^2}{1^2}}$$

$$p = 37{,}647 \text{ lbs. nearly per square inch of section.}$$

Theoretical Section.—The centre line of the pillar formed by joining the centres of gravity of the cap and base

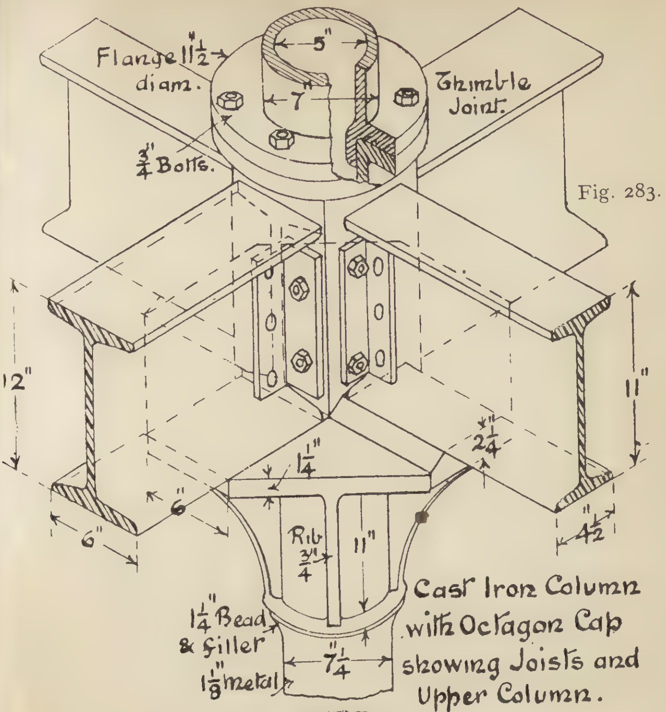


Fig. 283.

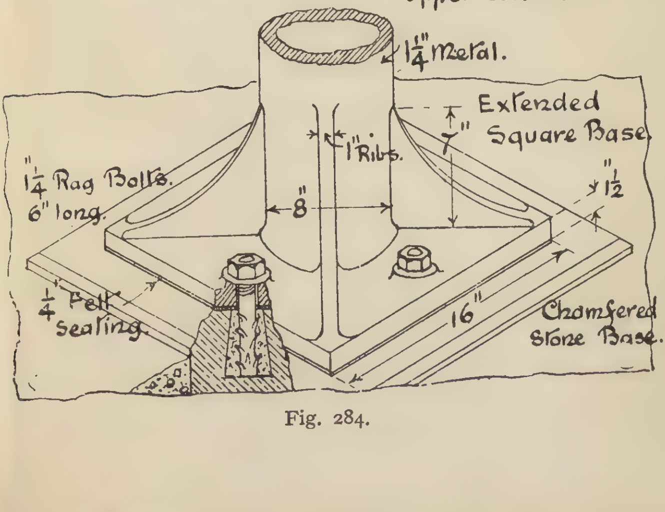


Fig. 284.

of a pillar, which should be fixed perpendicular to the pressure is known as the neutral axis, and as the value of the moment of inertia or the resistance to change is increased as the square of the distance of the metal from the neutral axis, the best theoretical section suggested is a hollow circle, which disposes of the material with the greatest advantage.

Hollow cast-iron columns practically satisfy this condition; timber posts are usually rectangular or circular, as in the case of squared timbers or scaffold poles, that being the market section, and wrought iron or steel pillars of the hollow square or flanged sections, the labour and expense being so great in forming the theoretical section in these latter materials as not to compensate for the advantage gained.

Care should be taken that the pressure on the pillar is evenly balanced, otherwise the tendency to bend will be increased, and the strength will be impaired.

In the case of wood beams, any tenons in the end should be deducted from the area, as the ends of the tenons should never fit tightly against the bottom of the mortice.

Bases and Caps.—Pillars supporting pillars should be jointed together with truly plane surfaces, and the axes in a right line, as shown in figures 283 to 290. Bases must be formed to distribute the pressure over a greater area of material of less compressional strength and to obtain a fixing, and the caps must be designed to receive main and transverse girders and columns where required. Figures 285 to 288 illustrate the fixing of girders to pillars. Care must be taken that the cap and base plates are properly stiffened, as shown in figures 283 and 284, and that the stiffeners have sufficient shearing area.

Boxings.—Properly formed cast-iron boxings, or stools,

Fig. 285. Fig. 287.

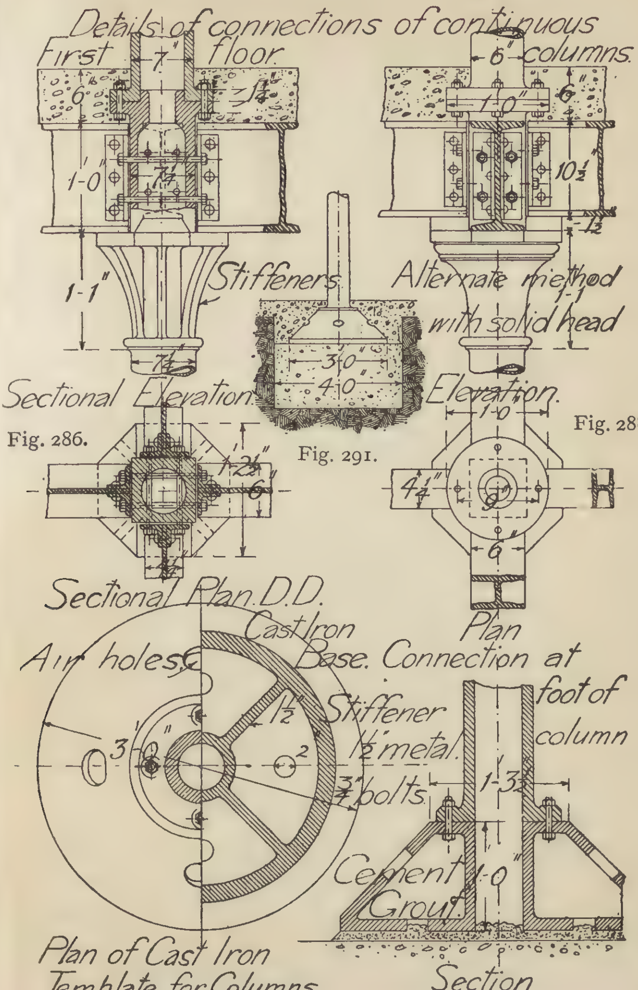


Fig. 286. Fig. 291. Fig. 288.

Fig. 289 Fig. 290.

are convenient and economical to bolt to the cap plates of wrought and cast-iron columns, to receive the main and transverse girders, and to form a fixing for superimposed pillars ; they are simply boxings with upper and lower compartments, with stiffeners directly under each girder. The lower side is bolted to the cap of lower pillar, the girders are bolted to the intermediate horizontal partition, and the upper surface forms a good fixing for the superimposed pillar, the bolts of which may be over the central compartments, as shown in figure 292, or over the side enclosures, which are more convenient for fixing. The boxings on cast-iron pillars are sometimes cast as part of the pillar, similar to that shown in figures 285 to 288.

Base.—It is usual for the lowest pillar to be directly supported by a large stone, to more effectually distribute the concentrated load over a great area. The upper surface of this stone is more effectively and economically brought to a level plane by dressing it when in position. A seating of sheet lead, millboard, or felt is usually placed between the base plate and the stone to obtain a uniform bearing and to reduce vibration.

To prevent lateral motion, small projections, termed lugs, are often cast to the base of cast-iron pillars, and these are fitted into a corresponding mortice in the stone base ; but in all cases, to ensure a certainty of being secure, bolts must be used, as shown in figure 284.

Owing to the difficulty in bedding a series of large stone templates, level in themselves and with each other, cast-iron bases have been devised to which a better fixing can be obtained and which can be more easily fixed in position. Figures 289 to 291 and 298 to 301 show types. It is usual to pack these in position and then to thoroughly fill in the bedding space with cement grout. Great care must be taken in these castings that every part is nearly uniform in

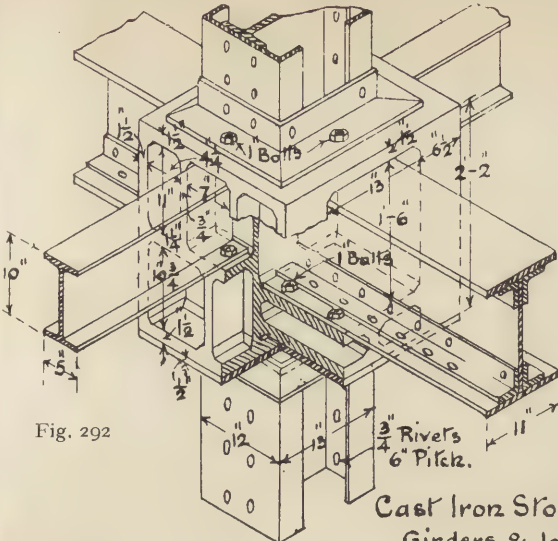


Fig. 292

Cast Iron Stool Cap, Girders & Joists.

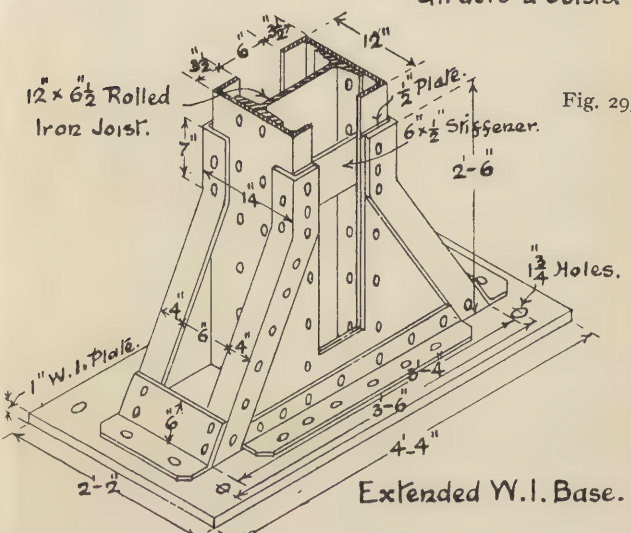


Fig. 293.

Extended W.I. Base.

Fig. 294. Fig. 295.

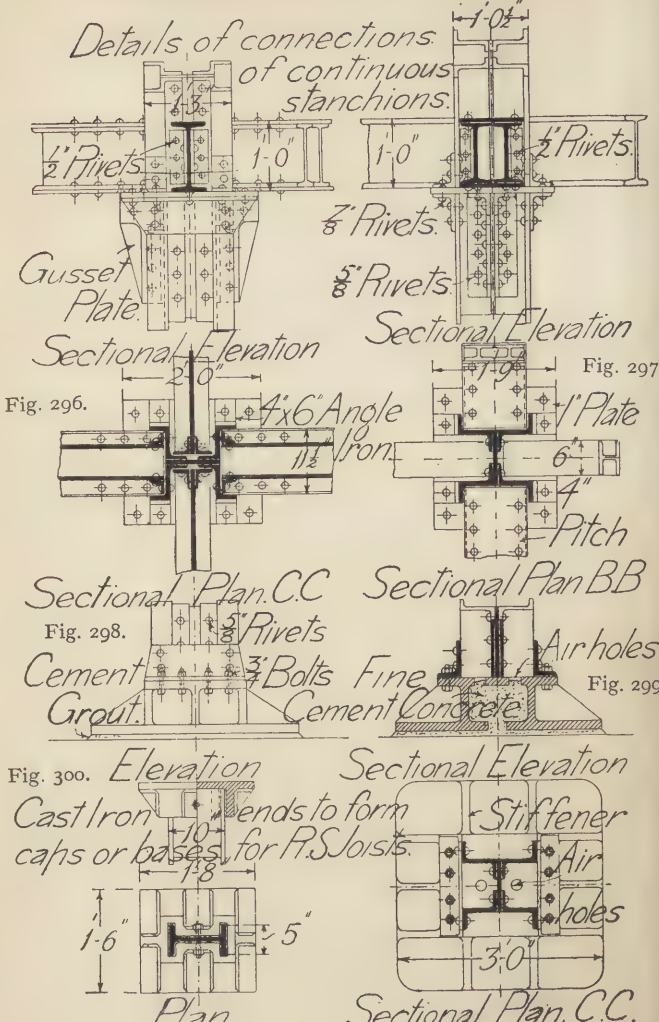


Fig. 296. Fig. 297. Fig. 298. Fig. 299. Fig. 300.

Fig. 302. Fig. 301.

thickness, and that the cooling operation is carried on gradually and equally, otherwise internal stresses will be set up which may cause the iron casting to fly at the slightest blow or sudden change of temperature. The ill effect of this defect is largely obviated by embedding the base in concrete when the first length of column has been erected.

Wrought Iron and Steel.—Angle, tee, channel, joist, plate and bar iron are riveted together to form the desired section of wrought-iron and steel girders. For heavy loads, the hollow, square, and hexagonal sections, as shown in figures 508 to 520, *Elementary Course*, are largely employed.

For economy and facility in construction those sections should be used for stanchions to which connections can easily be made at any part. To comply with this condition it is necessary that all the faces of the stanchions should be exposed to enable any connections to be riveted. The best sections are combinations of zed bars or the ordinary rolled joist sections, as shown in figures 294 to 301, which illustrate connections made to stanchions of the above form.

Figures 508 to 520, *Elementary Course*, give twelve typical sections of rolled iron and steel stanchions.

Revised Rankine Formula.—Of late years Rankine's formula has been modified. The value of "a" always requiring to be ascertained by experiment, was exceedingly difficult to find for any particular section and material. It will be found, first, that if the value of "a" be taken as the reciprocal of the limit of elasticity; secondly, that if $l^2 \div r^2$ be substituted for the $l^2 \div d^2$ of Rankine's formula, r being equal to the minimum radius of gyration; and thirdly, that a varying factor of safety equal to—

$$\left(4 + {\cdot}07 \frac{\text{length in inches}}{\text{least diameter in inches}}\right),$$

then a result will be obtained probably more satisfactory and reliable than that given by any other formula. The

advantage of this formula is that none of the factors are difficult to obtain.

In the following calculations the ultimate resistance of mild steel in compression is taken as 60,000 lbs. per square inch, and the limit of elasticity 40,000 lbs. per square inch. For any particular steel these two values should be obtained from the manufacturer, or if a particular value is required it should be specified.

The formula may be stated as follows:—

(1) $p = \dfrac{f}{1 + a\dfrac{l^2}{r^2}}$ for ends flat and fixed.

(2) $p = \dfrac{f}{1 + 2a\dfrac{l^2}{r^2}}$ for ends round jointed or hinged.

Factors of Safety.—The following factors of safety should always be used in conjunction with the revised formula for pillars under dead loads:—

$$\text{Factor of Safety} = 4 + \cdot 07 \frac{\text{length in inches.}}{\text{least diameter in inches.}}$$

Length. Diameter.	Factor of Safety.	Length. Diameter.	Factor of Safety.
3	4·21	55	7·85
6	4·42	60	8·20
9	4·63	65	8·55
10	4·7	70	8·90
12	4·81	75	9·25
15	5·05	80	9·60
18	5·26	85	9·95
20	5·40	90	10·30
21	5·47	95	10·65
24	5·68	100	11·00
25	5·75	105	11·35
27	5·89	110	11·70
30	6·10	115	12·05
35	6·45	120	12·40
40	6·80	125	12·75
45	7·15	130	13·10
50	7·50		

For live loads these values to be doubled.

Example.—Determine the safe strength of a mild steel

pillar, 8 in. × 6 in. rolled joist British Standard section, 35 lbs. per ft. run, with an area of 10·293 inches, minimum radius of gyration 1·32 inches, length of pillar 8 ft. 9 in.

$$\frac{l}{r} = \frac{105}{1 \cdot 32} = 80 \text{ nearly.}$$

then by formula—

$$p = \frac{f}{1 + a\frac{l^2}{r^2}} = \frac{60000}{1 + \frac{1}{40000} \cdot \frac{80^2}{1^2}}$$

$$= \frac{60000 \times 40000}{46400}$$

$$= 51724 \text{ lbs.}$$

$\frac{l}{d} = \frac{105}{6} = 17 \cdot 5$; then from table factor of safety $= 5 \cdot 26$.

then p for safety $= \frac{51724}{5 \cdot 26} = 9833 \cdot 5$ lbs.

$$\text{then P in tons} = \frac{Sp}{2240}$$

$$= \frac{10 \cdot 293 \times 9833 \cdot 5}{2240}$$

$$= 42 \cdot 173 \text{ tons.}$$

The following table gives the value of p in lbs. per square inch, calculated from the formula $p = \frac{f}{1 + a\frac{l^2}{r^2}}$ when $\frac{l}{r}$ equals from 5 to 200, $= 60000$, and "a" $= \frac{1}{40000}$ for mild steel pillars, ends flat and fixed.

$\frac{l}{r}$	Ultimate Resistance.	$\frac{l}{r}$	Ultimate Resistance.	$\frac{l}{r}$	Ultimate Resistance.
5	59,963	75	52,602	145	39,328
10	59,850	80	51,724	150	38,400
15	59,664	85	50,821	155	37,486
20	59,406	90	49,896	160	36,585
25	59,077	95	48,955	165	35,701
30	58,679	100	48,000	170	34,833
35	58,218	105	47,036	175	33,982
40	57,692	110	46,065	180	33,149
45	57,109	115	45,092	185	32,334
50	56,470	120	44,118	190	31,537
55	55,781	125	43,145	195	30,759
60	55,045	130	42,180	200	30,000
65	54,278	135	41,220		
70	53,452	140	40,268		

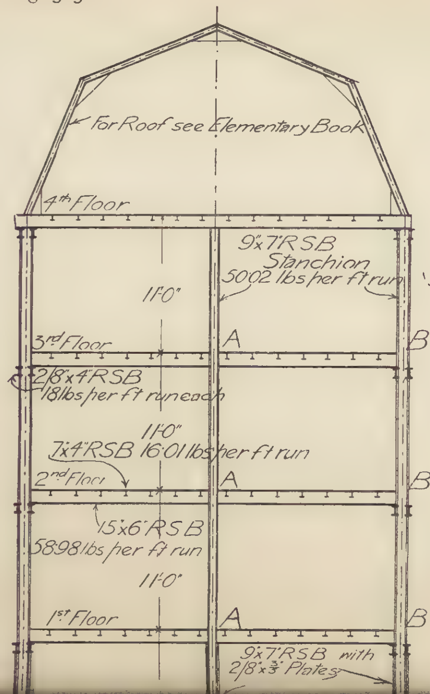
Steel Skeleton Construction.—The tendency of modern practice is to adopt the American system of fire-resisting construction, consisting of a steel skeleton clothed in concrete or vitreous materials. The objection to this system has hitherto been the anticipated slight dislocations in the structure resulting through the varying coefficients of expansion of the different materials employed. The introduction of steel, facilitating as it does the reduction of the sections, has enabled a system to be evolved in which buildings of great magnitude can be constructed economically and rapidly owing to the insertion of steel stanchions in the walls obviating the necessity for very thick walls. The objection to the unequal expansion of the column and its enclosing materials has been overcome by the insertion of horizontal girders between the columns, each supporting a given section of the vertical height of the wall. To such an extent has this principle been carried out that the wall has been commenced and carried on simultaneously at different heights after the steel frame has been erected, the horizontal girders practically cutting up the enclosing wall into a number of panels, each supported by its respective horizontal girder, which in its turn transmits the weight to the vertical stanchions. There can be no doubt about the unitedness of such a structure so perfectly framed, that wherever slight settlements are to be expected which would be fatal to structures built in the usual way, the maximum of resistance of each part has to be overcome before any portion can give way. The superiority of this system is also manifest wherever the operations to be carried on within the building are of a vibratory nature.

The earthquake shocks in San Francisco (1906) have corroborated and proved the efficiency of steel-framed buildings when subjected to great vibrations and shocks.

Steel Skeleton Calculation.—Example: Let a building be taken with five floors and a Mansard roof of the type shown

Steel Skeleton Construction.

Fig. 303.



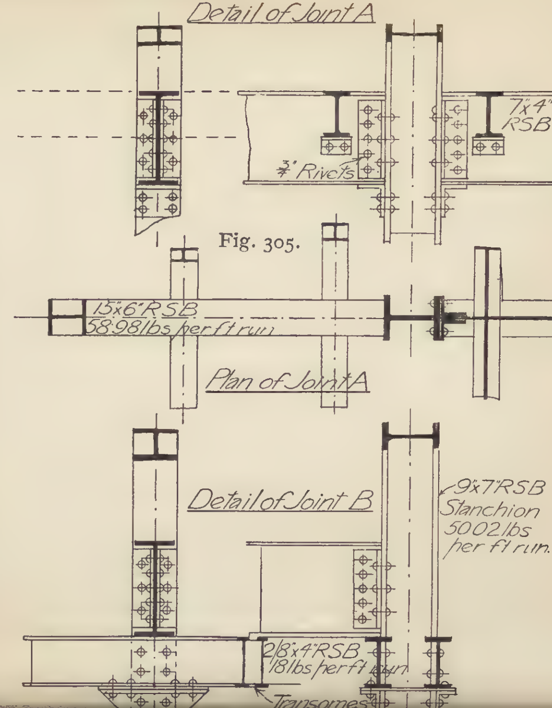
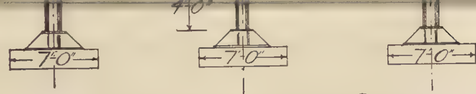
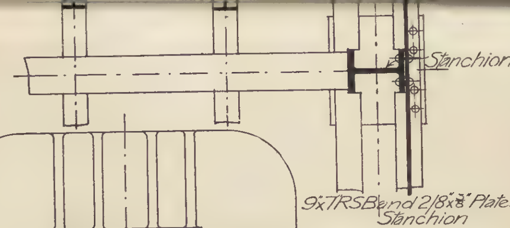


Fig. 305.

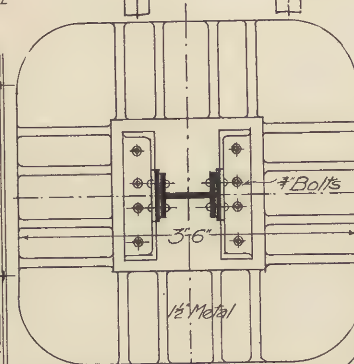


Vertical Section of Steel Skeleton



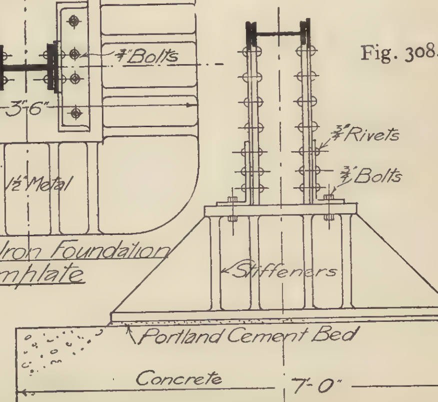
Plan of Steel Skeleton

Fig. 304.



Plan of Cast Iron Foundation Template

Fig. 307.



Elevation of Foundation.

Fig. 308.

[Between pages 390 and 391.

in figure 790, *Elementary Course.* Each storey to be 11 feet in height, the stanchions to be placed at 15 feet centres, 30 feet between the centres of the back and front stanchions of the building. The walls to be $1\frac{1}{2}$ bricks thick, the weight of brickwork 112 lbs. per cubic foot, load on each floor, including weight of the floor, to be 2 cwts. per cubic foot, the safe stress on the steel to be taken as 6 tons per square inch. From the figures 303 to 308 it may be seen that the dimensions of the joists at each floor level will be similar, and the stanchions will increase in dimensions from the top downwards as the load accumulates. Let the sections of the joists of the floors marked in figure 304 *a*, *b*, and *c*, be calculated.

Joist "*a*" is supporting the load of 2 cwts. per super foot on an area of 15 ft. × 2 ft. = 30 super feet and 30 × 2 = 60 cwts. distributed load, then by the ormula—

$$\frac{Wl}{8f} = \frac{I}{\delta}$$

$$\frac{60 \times 180}{8 \times 6} = \frac{I}{\delta}$$

$$\frac{I}{\delta} = 11{\cdot}25$$

then from the B. S. B. the nearest moment of resistance is 11·206 given by 7 in. × 4 in. beam having a weight of 16·01 lbs. per foot run.

Joist "*b*" is supporting the load on a floor area of 15 feet × 15 feet = 225 super feet and 225 cwts. × 2 cwts = 450 cwts. = 22·5 tons distributed load, then by the formula—

$$\frac{Wl}{8f} = \frac{I}{\delta}$$

$$\frac{22{\cdot}5 \times 180}{8 \times 6} = \frac{I}{\delta}$$

$$84{\cdot}375 = \frac{I}{\delta}$$

then from the British Standard sections of steel beams the

nearest moment of resistance is 83·879 given by 15 in. × 6 in. joist having a weight of 58·98 lbs. per foot run.

Joist "*c*" supports the section of wall 15 ft. × 11 ft. × 1 ft. 6 in. thick; total weight will equal 15 × 11 × 1·5 × 1 cwt. = 247·5 cwts. = 12·375 tons distributed load, then by the formula—

$$\frac{Wl}{8f} = \frac{I}{\delta}$$

$$\frac{12·375 \times 180}{8 \times 6} = \frac{I}{\delta}$$

$$46·406 = \frac{I}{\delta}$$

then from the B. S. B. an 8 in. × 4 in. steel joist, 18 lbs. per foot run, gives a moment of resistance of 22·339. Let two of these be taken spaced and bolted to have a surface area of 13 inches.

Central Stanchion.—Commence the calculations from the top floor and work downwards. The area of each floor supported by stanchion is 15 ft. × 15 ft., and the total load = 15 × 15 × 2 cwts. = 22·5 tons.

The load at each level will be as follows:—

4th floor	supports	22·5	tons.
3rd ,,	,,	45·0	,,
2nd ,,	,,	67·5	,,
1st ,,	,,	90·0	,,

For convenience in riveting cross-beams "b" a section 7 inches wide is necessary. From the B. S. B. list let a 9 in. × 7 in. beam, 50·02 lbs. per foot run and 17·64 sectional area be selected. The minimum radius of gyration is 1·647, the length is 11 feet $\therefore \frac{l}{r} = \frac{132}{1·647} = 80·146$, and from the table given the ultimate resistance to compression = 51724 lbs. The $\frac{l}{d} = \frac{132}{7} = 19$ nearly, and from the table the factor of safety = 5·26.

$$\therefore p \text{ for safety} = \frac{51724}{5·26 \times 2240} = 4·3899 \text{ tons}$$

$$\therefore P = Sp = 17·064 \times 4·3899 = 74·738 \text{ tons}$$

This section will, therefore, be sufficient down to the first-floor level.

From the first-floor level to foundations the area of the stanchion must be increased by riveting plates on each flange. Let an 8 in. × $\frac{3}{8}$ in. plate be riveted to each flange. Then

$$p = \sqrt{\frac{I_1 + I_2}{m_1 + m_2}}$$
$$= \sqrt{\frac{46{\cdot}25 + 32}{17{\cdot}064 + 6}}$$
$$\sqrt{\frac{78{\cdot}265}{23{\cdot}064}}$$
$$= 1{\cdot}8421.$$

The length is 15 feet $\therefore \frac{l}{r} = \frac{180}{1{\cdot}8421} = 97{\cdot}71$, and from the table the ultimate resistance to compression is 48000 lbs.

$\frac{l}{d} = \frac{180}{8} = 22{\cdot}5$, and from the table the factor of safety $= 5{\cdot}47$

$\therefore p$ for safety $= \frac{48000}{5{\cdot}47 \times 2240} = 3{\cdot}9185$ tons

$\therefore P = S\,p = 23{\cdot}064 \times 3{\cdot}9185 = 90{\cdot}353$ tons.

External Stanchion.—Commence the calculations as before, working downwards.

Level.	Roof.	Wall.	Floor.	Increment at each level.	Total in Tons.
4	5·13	·4	11·25	20·38	20·38
3		12·375	11·25	23·625	44·005
2		12·375	11·25	23·625	67·63
1		12·375	11·25	23·625	91·255

Using similar sections as in the central stanchion, it will be seen that the 9 in. × 7 in. beam will be sufficient to the first floor level, and the 9 in. × 7 in. beam with the 8 in. × $\frac{3}{8}$ in. plates will be sufficiently near for the lowest portion of this stanchion.

Determination of Number of Rivets.—For the computation of the riveted connections it will be necessary to satisfy the four conditions to economically dispose the rivets, as given in the article on Riveting in the chapter on Girders.

For the minimum number "n" of rivets required at each section to resist the shearing and bearing stresses, the following formulæ may be used :—

$$n = \frac{\text{total stress}}{\text{safe resistance in single shear of the rivets used}}$$

$$n = \frac{\text{total stress}}{\text{safe bearing strength of the rivets used.}}$$

The following table gives the safe working values for single shear for rivets or bolts from $\frac{1}{4}$ in. to 2 in. diameter, and the safe bearing values of rivets from $\frac{3}{8}$ in. to 2 in. diameter in plates from $\frac{1}{4}$ in. to 1 in. in thickness. If the plates joined are unequal in thickness, the thinner plate is the thickness of the plate calculated for bearing area.

Shearing and Bearing Values for Bolts and Rivets.

Maximum working loads, shearing 11200 lbs., bearing 15000 lbs. per square inch for mild steel.

Diameter of Rivet.	Area in Square Inches.	Single Shear in lbs. per Rivet.	Thickness of Plates Joined.									
			$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
$\frac{1}{4}$	·0490	549	—									
$\frac{3}{8}$	·1104	1237	1410									
$\frac{1}{2}$	·1963	2198	1880	2340	2810							
$\frac{5}{8}$	·3068	3436	2340	2930	3520	4100						
$\frac{3}{4}$	·4417	4946	2810	3520	4220	4920	5630	6330	7030	8440	9850	11250
$\frac{7}{8}$	·6013	6733	3280	4100	4920	5740	6560	7380	8200	9840	11480	13120
1	·7854	8797	3750	4687	5625	6562	7500	8437	9375	11250	13125	15000
$1\frac{1}{8}$	·9940	11133	4219	5273	6328	7383	8438	9492	10547	12656	14766	16875
$1\frac{1}{4}$	1·2272	13755	4688	5859	7031	8203	9375	10547	11719	14063	16406	18750
$1\frac{3}{8}$	1·4849	16631	5156	6445	7735	9024	10313	11602	12891	15469	18047	20625
$1\frac{1}{2}$	1·7671	19791	5625	7031	8438	9844	11250	12656	14063	16875	19688	22500
$1\frac{5}{8}$	2·0739	23226	6094	7617	9141	10665	12188	13711	15235	18282	21329	24375
$1\frac{3}{4}$	2·4053	26876	6563	8203	9844	11485	13125	14766	16407	19688	22969	26250
$1\frac{7}{8}$	2·7612	30854	7032	8789	10547	12305	14063	15821	17579	21094	24610	28125
2	3·1416	35105	7500	9375	11250	13125	15000	16875	18750	22500	26250	30000

Calculations of the Connections.—The joist "a" is shown supported at the ends by 3 in. × 3 in. × $\frac{3}{8}$ in. steel angles as shown in figure 305. The reaction at each end of the joist = 30 cwts. = 3,360 lbs.

In all these connections, for the purpose of uniformity let $\frac{3}{4}$ inch diameter rivets be used—

$$\therefore \text{ for shearing } n = \frac{3360}{4946} = 1 \text{ nearly}$$

$$\therefore \text{ for bearing } n = \frac{3360}{4220} = 1 \text{ nearly}$$

To prevent rotation two rivets would be necessary. The minimum length of steel angle = $d\,(1 + 1 + 1\frac{1}{2} + 1 + 1) = 5{\cdot}5 \times {\cdot}75 = 4{\cdot}125$ inches.

Considering beam "*b*" the reaction at each end = 22·5 ÷ 2 = 11·25 tons = 25,200 lbs. The beam is shown in figure 306, supported by 4 in. × 3 in. × $\frac{1}{2}$ in. steel angles—

$$\therefore \text{ for shearing } n = 25200 \div 4946 = 5{\cdot}1, \text{ say } 6$$
$$\therefore \text{ for bearing } n = 25200 \div 5630 = 5 \text{ nearly}$$

Six rivets will therefore be necessary to secure the steel angles to the stanchion to resist single shear, and five to secure the steel angles to beam "*b*" as these rivets will be in double shear. The minimum length of the steel angle will equal $d\,(1 + 5 + 6 + 1) = 13 \times {\cdot}75 = 9{\cdot}75$ inches.

Considering the connection of beam "C." This being made up of two 8 in. × 4 in. steel joists, as shown in figure 306, the reaction at the extremities of each will be 12·375 ÷ 4 = 3·0937 tons = 6930. This is supported by 5 in. × 3 in. × ·5 steel angles—

$$\text{for shearing } n = \frac{6930}{4946} = 1{\cdot}4$$

$$\text{for bearing } n = \frac{6930}{5630} = 1{\cdot}23$$

Two rivets will be necessary and the minimum length of the angles will equal $d\,(1 + 1 \quad 1\frac{1}{2} + 1 + 1) = 5{\cdot}5 \times {\cdot}75 = 4{\cdot}125$ inches.

CHAPTER VIII.

GRAPHIC STATICS.

Calculations.—The calculation of buttresses, retaining walls, arches, girders, trusses, and such constructions which resolve themselves into statical problems, may be accomplished in two ways: (1) By pure mathematics; (2) by graphic statics.

The first method gives results correct to any required number of decimal places.

The graphic method gives results varying according to the accuracy and sensibility of the mathematical drawing instruments used, together with the carefulness and skill of the operator; and provided these conditions are absolutely satisfied, correct results would be obtained in a very short time. The diagram (if mathematical accuracy is desired) should be drawn with units, the lengths of which are not less than a thousand times the thickness of the lines employed; and with good instruments, judgment and care, the answer would probably be correct to within a 1000th part of itself, which, according to Lock the mathematician, is quite satisfactory for ordinary practice, and added to this any error in the equilibrium of the forces is evident by inspection of the diagram, which makes this method invaluable as corroborative evidence, even though trigonometrical calculations are used.

It would probably be true to say that in ordinary practice answers would be obtained by the graphic method

correct, or with a maximum error of 100th part of itself, and when it is remembered that for safety the strength of parts is made from four to ten times the calculated breaking strengths, an error of 100th part, although undesirable, is practically immaterial.

Necessary Knowledge.—It is necessary that the student should have mastered the principles of the parallelogram, triangle and polygon of forces as given in works on theoretical mechanics, *e.g.*, "Lock's Statics," and the proof of the statical propositions which are assumed in this work is ably given in "Lock's Elementary Statics" and "Graham's Graphic Statics." The propositions only therefore will be stated upon which the science of statics is built, and the application will be given as a number of operations.

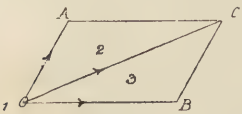


Fig. 309.

Force or Vector Description.—A force or vector is said to be known when its (*a*) magnitude, (*b*) direction, (*c*) sense, and (*d*) point of application to a rigid body is known. A vector is specified when (*a*) (*b*) and (*c*) only are known. The length of a line may be made to represent magnitude to scale. The direction is expressed by arrowheads, or if the extremities of the forces are lettered, the conventional method is to express the starting-point before any other point in its pathway. Thus, in describing the direction of a force as A B, it would mean that the direction of the force is transmitted from A to B, but it will be generally better to describe bars by the numbers on either side. Thus, O A would be 1—2, O B would be 1—3, and O C would be described as 2—3 in the figure 309, and to determine the sense of the stresses afterwards. The point of application is readily shown in a diagram, and is that point on a rigid body offering resistance to a force.

Sense of the Stresses.—The bars of a system are probably

most surely and satisfactorily determined to be in tension or compression by taking each of the reciprocal figures of the nuclei of the frame polygon, separately from the stress diagram, making the arrows on the forces the same direction about the figure. Thus, in the example of the king-post truss, let that reciprocal of the forces and bars of the frame polygon about the nucleus, P—1—8—9, figure 328, be drawn separately, as in figure 330. Then by the proposition of the polygon of forces, to be in equilibrium, these forces must be cyclic, *i.e.*, all of the same way round, taken in order. The directions of forces 9 P and P—1 are known, therefore all the others are known, and this knowledge in any such figure of all but two forces is essential for the drawing and solution.

The arrows must then be drawn in the same direction on the frame polygon as on the reciprocal force polygon of the nucleus, indicating same near the nucleus taken.

Arrows must be then drawn at the opposite extremity of each bar, but with a reverse direction, as shown in figure 328. Bars having arrows pointing outwards will be under compression, as 1—8; and those having arrows pointing inwards will be resisting tension, as 8—9 in the figure 328.

The Parallelogram of Forces.—When two forces 1—2, 3—1, figure 309, acting concurrently at a point are represented in magnitude and direction by two lines O A, O B, then their resultant will be represented in magnitude and direction by the diagonal O C of the parallelogram.

If the direction of the diagonal 2—3 is reversed, it becomes the equilibriant of the forces O A, O B.

The Triangle of Forces.—When three forces 1—2, 2—3, 3—1, figure 310, in one plane act at a point, and a triangle (figure 311) has two of its sides 3—2, 2—1, taken the same way round, parallel and proportional to two of the forces 1—2, 2—3, then the necessary and sufficient condition that

the forces 1—3, 3—2, 2—1, may be in equilibrium is, that the third force 1—3 is parallel and proportional to the third side, taken the same way round, 1—3 of the triangle 3—2—1.

The Polygon of Forces.—When any number of forces act at a point, they are, or are not, in equilibrium, according as the polygon formed by drawing lines the same way round, parallel and proportional to the forces, is, or is not, a closed polygon. P 1, 2, 3, 4, Q 10, 9, of figure 329, is a closed force polygon, and the forces are in the same direction taken the same way round, it is, therefore, in equilibrium.

Reciprocal Figures.—Two figures are said to be reciprocals when the lines composing them fulfil the two following conditions:—1st, That their lines are respectively parallel or perpendicular to each other; 2nd, that lines radiating

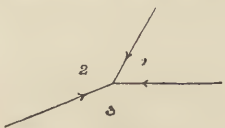


Fig. 310.

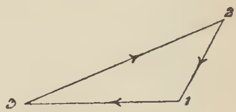


Fig. 311.

from a point in one figure are parallel or perpendicular to corresponding lines forming in the other a closed polygon.

Technical Terms.—The outline of the frame or truss under investigation is termed a frame polygon, the angular points at which three lines meet (any line of which may be an external force or bar, but no two in the same straight line) is termed a nucleus, the reciprocal figure to the external forces shown on the frame polygon is termed the force polygon, the reciprocal figure to the polar lines is the funicular polygon, the reciprocal figure to the frame polygon or the lines of stress is the stress polygon.

Polar Polygon.—The reciprocal figure to the polar lines is termed the polar polygon, which may be either (1) a funicular (or rope) polygon as A*bcdefgh*K in figure 324, where

those members could be imagined to be in equilibrium when each part is subjected to tension having the magnitude of the reciprocal polar line, thus *b*—*c* would be in tension with a stress equal to polar line O—1, measured by the unit used for the force polygon; or (2) a linear arch as in M*mlkhgfe*N, figure 317, where the bars could be imagined to be rigid rods subjected to compression of the magnitude represented by the reciprocal polar lines.

Notation.—It will contribute to the easiness of working if the spaces between the forces and bars in the frame polygon are numbered, and any force or bar will be described by the numbers on both sides; the stresses on the force polygon, and stress diagram, and polar lines, will be easily described by the numbers at the extremities of the lines, whilst each member of the polar polygon will be known by the space in the frame polygon that it traverses.

Limits of Application.—To be possible to apply the laws of graphic statics for all conditions of loading and fixing, all frame polygons must (1) be built up of a number of bars forming a triangulated system, and if S = number of bars, p = number of angular points, then S = $2p$—3, which is the relation that sides and angular points of all triangles have to each other; (2) three forces at least, no two being in the same straight line, must radiate from each of its nuclei, or the figure must be considered to be solid and unalterable.

The ordinary Queen and Mansard roof trusses fail to comply with the laws of graphic statics, and are manifestly constructionally unsafe, only being made to answer their purpose by the aid of iron fastenings, the latter taking the place of brace bars, and therefore will be subjected to the stresses on the displaced bars as shown in figures 339 and 340.

Centre of Two Parallel Forces.—The centre of two parallel forces may be obtained by drawing ordinates, as C A, D B, perpendicular to a line A B. as shown in figure 313, with

values inversely to the loads C A, D B :—1st, the forces having the same direction, by making lines joining the free extremities of the ordinates to the base of opposite ordinate. The intersection of these lines will be a point E, as shown in figure 313, which is in the pathway of the resultant, which is then drawn, the magnitude of R being the algebraical sum of the forces, which in this case is $2+5=7$; 2nd when the forces have opposite directions, by joining with a line the free extremities of the ordinates, as C D,

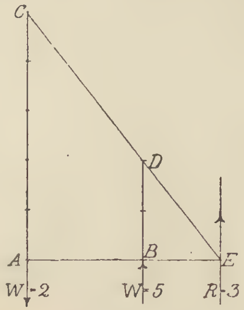


Fig. 312.

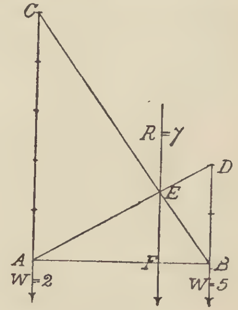


Fig. 313.

figure 312, and producing the same till it cuts the line A B produced at E, this will be a point in the pathway of the resultant, the value of which will be the algebraical sum of the forces, and in this case equals $-2+5=3$.

C G of a Triangle.—The centre of gravity of a triangle is obtained by drawing lines joining the centre points of two sides to the opposite angles, as D B and E A in figure 314; the intersection F is a point, which in all triangles is one-third of the distance from the centre of the base to the apex.

C G of a Quadrilateral Figure.—This may be determined by imagining the quadrilateral to consist of pairs of triangles, using figure 315 :—1st, of A B D and C B D, and joining their centres of gravity E F, by a line which will contain the C G of the quadrilateral; 2nd, of D A C and

B A C, and joining their centres of gravity, K H, which latter contains the C G of the quadrilateral. The C G of the whole figure must be the intersection *cg* of E F and K H. In like manner the centre of gravity of any polygon could be found. The centre of gravity of a solid cone or pyramid is at a point situated one-fourth of the length from the base of a line joining the centre of the base and its apex. The knowledge of the above will be assumed and the centres of gravity of figures of uniform density with the value of the resultant of the forces will be taken as granted in the elucidation of following problems.

The determination of the centres of gravity of complicated irregular figures will be given later in this chapter.

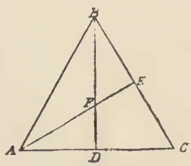


Fig. 314.

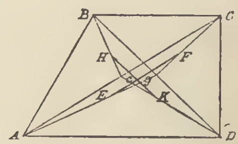


Fig. 315.

Application.—Difficulties in the solution of statical problems will be cleared away if the student observes the following order of operations :—

(1) Draw the proposed frame polygon, and note, if an open frame, if it satisfies the condition $S = 2p—3$.

(2) Position of forces, including reactions (exact or approximate).

(3) Notation.

(4) Draw as much as possible of the force polygon, leaving only two forces of which the two directions, or the two magnitudes, or the two magnitudes and one direction are to be determined, the algebraical sum of these effects with one direction only being known.

(5) Draw polar point, and all polar lines but one.

(6) Draw the polar polygon.

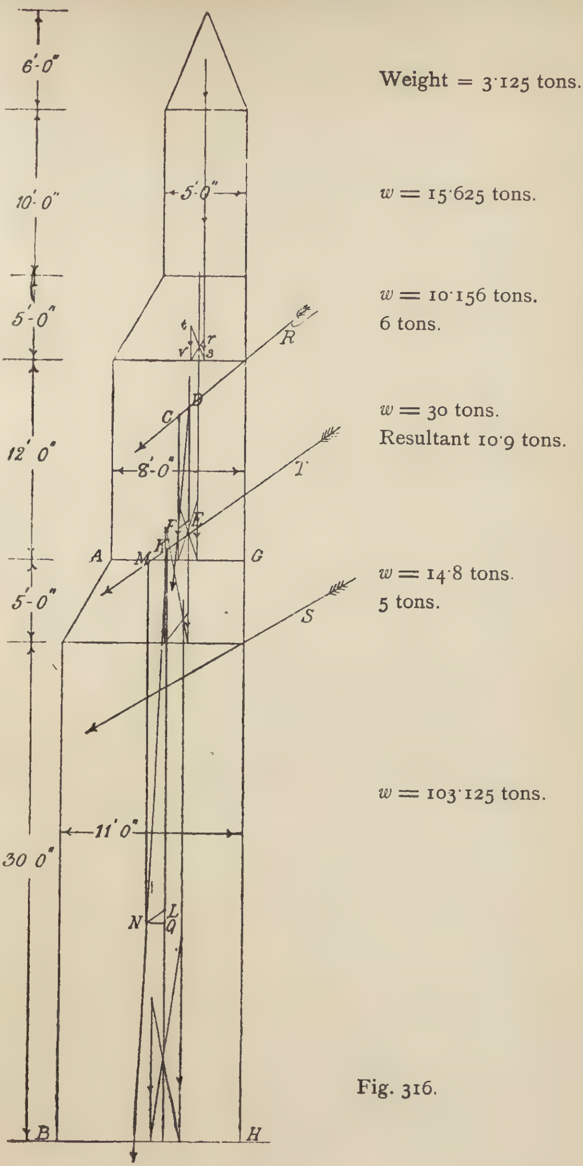

6'0"
10'0"
5'0"
12'0"
5'0"
30'0"
5'0"
8'0"
11'0"
R
T
S
A
G
B
H
Weight = 3·125 tons.
w = 15·625 tons.
w = 10·156 tons.
6 tons.
w = 30 tons.
Resultant 10·9 tons.
w = 14·8 tons.
5 tons.
w = 103·125 tons.

Fig. 316.

(7) Determine reactions by drawing the reciprocal polar line of the closing line of polar polygon to intersect the reaction, the direction of which is known. The line closing the force polygon will give the magnitude and direction of the unknown reaction.

(8) Draw stress diagram.

Example I.—A buttress of masonry weighing 140 lbs. per cubic foot, having the form of accompanying diagram (figure 316), and of a uniform thickness of 5 feet, with a pyramidal top, has to sustain the two thrusts shown. Determine if the buttress is likely to overturn about A or B.

To obtain the Weight.—The figure may be considered to be made of six blocks. First determine the weight of each block, and find the vertical line in which the mass may be supposed to be collected, and acting through the force of gravity.

In this example it is only necessary to determine the weight of each block, starting with top, and to be able to obtain the centres of gravity of prisms, pyramids, and blocks of quadrilateral section, and by means of the method shown, obtain the centre of parallel forces, and find the resultant pressure of No. 1 and No. 2 blocks, then the resultant of three blocks, then the resultant which is shown as D F in the diagram of the four blocks and the upper thrust R.

Taking the line R, representing the upper thrust, produce it, and at the point of intersection with the vertical line representing the pathway of the aggregate pressure of the mass of the four blocks, draw a parallelogram, the side C D being set out to scale with measure—6 units, and D E 58·9 units; the line D F will give the resultant pressure to scale and the direction.

The buttress at this joint will be safe (1) from overturning if the resultant falls within the base A G, and

(2) if it intersects within the middle third will be safe from compression at that section, provided that the quotient of twice the normal pressure divided by the area of the section does not exceed per unit of sectional area the compressional strength of the material, and (3) will be safe from sliding if the angle between the resultant D F and F C does not exceed the angle of which four-fifths of the co-efficient of friction of the material is the tangent, as is fully described in the chapter on Brickwork.

In a like manner, the section at B H may be tested by obtaining :—1st, the sum of the total vertical loads and the centre of pressure at which it may be supposed to act; 2nd, the resultant T of the two thrusts R and S. Let these be represented by K L and K M, then K N shall be the resultant pressure. The total normal compression is K Q, which is the value of the vertical component of the thrust K N, and it is well to note that the buttress is safe from overturning and compression at the bed joint B H.

Uncemented Blocks.—Rule for the stability of structures of uncemented blocks (Wray) :—(1) The resultant of all the forces applied above any bed joint of a structure of uncemented blocks, including the weight of the structure above that bed joint, must intersect that bed joint sufficiently far inside its outer edge to ensure that the maximum intensity of the pressure does not exceed the bearing strength of the material. (2) The maximum intensity of pressure = twice its mean intensity = twice the normal component of the whole resultant pressure ÷ by the number of units into three times the distance from the edge of maximum pressure (provided that distance be not greater than one-third the width of the joint).

Arches composed of incompressible voussoirs (hard bricks and stones practically satisfy this condition) may be considered to be kept in equilibrium by three forces :—(1) the

force of gravity acting upon the total load (which latter includes the sum of the weight supported and the voussoirs) at its centre of gravity; (2) and the reactions of the two abutments; but it is convenient to consider one-half of an arch which may be considered to be kept in equilibrium by the three forces; (1) the force of gravity acting upon the total load at its centre of gravity between the crown and the abutment; (2) the horizontal thrust taken at the upper point on the middle third of section as shown at *c*, figure 318; and (3) the reaction of the abutment acting at the lowest point of the middle third of the skewback, as at figure 318. It may be noticed that the positions indicated for these thrusts will be points in Moseley's *line of least resistance*, that is, they are points in the pathway of the least force necessary to keep in equilibrium the weight of the mass and to satisfy the three conditions of equilibrium of uncemented blocks given in the chapter on Brickwork, and which is not here repeated.

Let W = the total load
P = the distance of centre of gravity of W from *a*
Q = horizontal thrust on the crown acting at *c*
h = perpendicular distance from *a* to *c*

Then by the theory of moments, using diagram,

$$W \times P = Q \times h$$

W is generally given, P and h can be measured from diagram, then Q can be deduced

$$Q = \frac{W \times P}{h}$$

Keystone, Depth.—Rankine gives the minimum depth in feet of a keystone for a single arch = $\sqrt{\cdot 12 \times \text{radius at crown}}$; depth of a keystone for an arch of a series = $\sqrt{\cdot 17 \times \text{radius at crown}}$.

EXAMPLE II.—Determine whether the line of least resistance will come within the middle third of the voussoirs of:—

A stone arch 10 feet span, 5 feet 9 inches radius, 1 foot

deep, and 2 feet thick, carrying the following loads on each side of centre of the key, 1, 3, $3\frac{1}{2}$, 4, $4\frac{1}{4}$, $4\frac{1}{4}$, and 4 tons.

The order of the eight operations given will be followed and worked:—

(1) *abcd*, in figure 318, is the middle third of the voussoirs, and is practically under compressional stresses only, and for the purpose of investigation may be considered a solid unalterable frame.

(2) Force 7—8 is the algebraical sum of the load and voussoir, and its position is obtained as shown in figure 313, the weight of the voussoir being taken as 2 cwts., and the superincumbent load as 78 cwts. The other vertical forces have been determined in a similar manner. Force Q is horizontal, and for the present R may be imagined to be in any reasonable direction passing through or near point *a* of the middle third.

(3) Number the spaces as shown, Q being now denoted by 1—9, and R being known as 8—9.

(4) Draw the force polygon 1—2, 2—3, 3—4, 4—5, 5—6, 6—7, 7—8 parallel to the reciprocal loads on the frame polygon, and to a length representing the magnitude of the forces, and draw a line of indefinite length passing through point 1, parallel to the force Q, its magnitude being unknown, the direction and magnitude of R being also unknown.

(5) In selecting the position of the polar point, it is usual in arch diagrams to pitch O somewhere in the horizontal line through 1, and draw polar lines by joining to the angular points of the force polygon 1 to 8. The polar point is not compulsorily pitched in any particular place; but it is more convenient, in the majority of problems, to place the polar point somewhere about vertically between the two known extreme points, and as far away as is possible on the paper. This will make possible a convenient reciprocal polar polygon.

(6) Operation No. 6 will determine the centre of the parallel vertical forces 1—2, . . . and 7—8, by drawing at any convenient point outside frame polygon through space 1, which is the space between bars 2—1, and 1—9, Ne, a

Fig. 317.

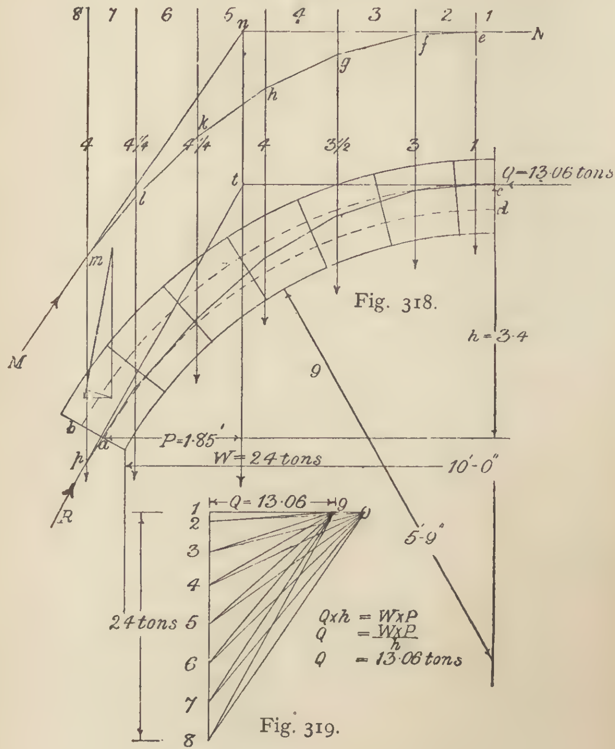


Fig. 318.

Fig. 319.

parallel of indefinite length to polar line O—1, figure 319, and its pathway intersects 2—1 at e; then from e across space 2 draw a parallel to polar line O—2, till it intersects 2—3 at f, and so on till a parallel to polar line O—7 is drawn across space 7, and cuts force 7—8 at m, from this

point draw a parallel to polar line O—8, till it intersects N*e* produced, the parallel to polar line O—1, in the point *n*. Such an arrangement of lines as N*efghklm*M is called a linear arch, as the two outside lines may represent forces pressing inward keeping the system in equilibrium, and the thrusts *ef*, *fg*, and so on, offering resistance to the value of the reciprocal polar lines.

The point *n* is a point in the pathway of the resultant of the vertical loads, and will therefore give a system of forces in equilibrium, not as in this case necessarily the required system of forces; but, as an equilibriant system to meet this case must have the same common resultant, the point *n* of this, or any equilibriant system, will give a point in the pathway of the resultant. The direction of the latter is obtained from the force polygon, and is parallel to 1—8, that is in this case vertical.

(7) The required polar polygon can now be commenced by drawing the horizontal thrust Q through *c* till it intersects the resultant force W at *t*; the reaction of the buttress to produce equilibrium must pass through *p* and *t*, point *p* being the intersection of the line of least resistance with the force 7—8. By drawing polar line O—9 parallel to Q*t* to intersect 8—9 of the force polygon, which latter must be drawn from point 8 parallel to *pt* of the polar polygon R*ptc*Q the reactions 8—9 and 9—1 are now determined.

(8) From the point 9 draw lines to the angular points of the force polygon, then the lines 9—1, 9—2, 9—3, 9—4, 9—5, 9—6, 9—7, 9—8 are the stresses on the arch and form the stress polygon, which when measured give the values of the stresses; the linear arch is completed by drawing parallels to these polar lines as shown in figure 318; thus by drawing across spaces 2—7, commencing at the intersection of 1—9 with load 1—2, parallels to stress lines 9—2, 9—3, and so on as shown, the line of least resistance or linear arch will be formed, when by inspection it can be determined

whether it is in safe equilibrium by satisfying the conditions of stability for uncemented blocks already given in this chapter, and in the chapter on Brickwork.

Arch Design.—Arches might with advantage be designed according to the load carried, thus heavy loads at the crown would be most economically supported by pointed arches; symmetrically concentrated loads, as girders or columns over the haunches would be satisfactorily carried by the elliptical or segmental form; whilst symmetrically distributed loads would suggest semi-circular or segmental arches.

The application of the foregoing principles has been applied to the design of a bridge in the chapter on Masonry.

Shearing Stresses and Bending Moments.—The determination of shearing stresses upon beams supported at both ends and carrying loads may be obtained graphically, as shown in figure 323. Let P—Q, drawn, say, to a lineal scale of ¼ inch = 1 foot, be a beam supported at both ends and carrying the loads P—1, 1—2, 2—3, and 3—Q. The order of the operations 1 to 3 having been satisfied, comply with operation 4 by drawing as much as possible of the force polygon, viz., P—1, 1—2, 2—3, 3—Q, and then (operation 5) place a polar point O, and draw a line *oh* perpendicular to the resultant P Q, so that this perpendicular line or polar distance, measured by a scale of forces, say ·1 inch = 1 cwt., shall be some multiple of ten, the reason for which will be stated presently. Then comply with operation 6 by drawing polar polygon, after which (operation 7) complete the force polygon, determining Q—4, 4—P, by drawing from the pole the reciprocal to the closing line of the polar polygon.

Draw shearing stress diagram by lines drawn perpendicular to force polygon from P, 1, 2, 3, Q and 4, and intersect these by continuing the force lines 4—P, P—1, 1—2, 2—3, 3—Q and Q—4; then shall the ordinates, such as *y*, in this diagram, which is shaded, measured perpendicularly to *y*—*y*,

give the shearing stress at any point x in the length of the beam.

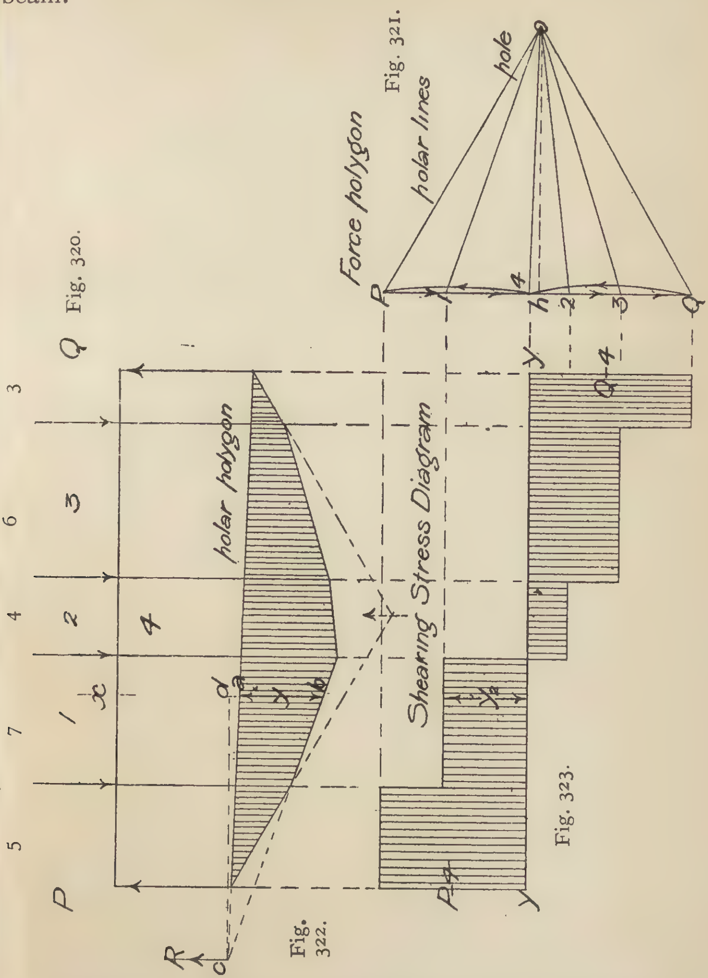


Fig. 320.

Fig. 321.

Fig. 322.

Fig. 323.

The bending moment at any point x in the beam may be shown to be proportionate to the length of the ordinate y of

the polar polygon at that cross-section. Using diagram (figure 322), continue the two sides of the polar polygon cut by the line $a—b$ till they intersect in c; then shall triangle cab of polar polygon be similar to the triangle 1—O—4 of the force polygon:

$$\text{then} \quad \frac{ab}{ca} = \frac{1-4}{o-4}$$

$$\text{but } cd : ca :: oh : o4$$

$$\therefore \quad \frac{ab}{cd} = \frac{1-4}{oh}$$

$$\therefore \quad ab \cdot oh = 1-4 \cdot cd$$

but 1—4 is the value of the resultant pressure on the left-hand side of x, and cd is the distance from x at which this resultant would act; that is, therefore, by definition, the bending moment at that point.

If lineal units are in feet and force units in cwts.

$\therefore$ ab in lineal units $\times$ oh in force units = bending moment at x in ft. cwts.

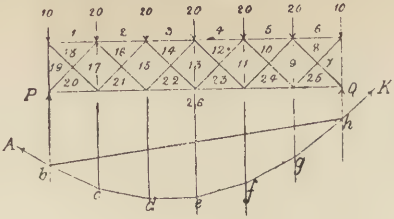
If oh has been drawn ten force units long it is easy to measure the bending moments, by making the lineal scale already used read in bending moments, oh times its numerical lineal value.

Lattice Girder.—EXAMPLE III.—Determine the stresses on the members of a lattice girder covering a span of 60 feet and the depth of which is 10 feet, and having lattice bars, as shown in figure 324 at an angle of 45°.

Application.—The order of the eight operations should be followed and worked.

The general method of application is, after what has been said about the arch, unnecessary, and only those points in which it differs in principle will be noted, and the only undiscussed problem will be found to be the value of the stresses on Q 7 and P 19. This is easily reasoned out by the elucidation given in the chapter on Girders, viz., let each triangulated system be supposed to carry, as it actually does, only the loads on its own system; then the pressure

Fig. 324.



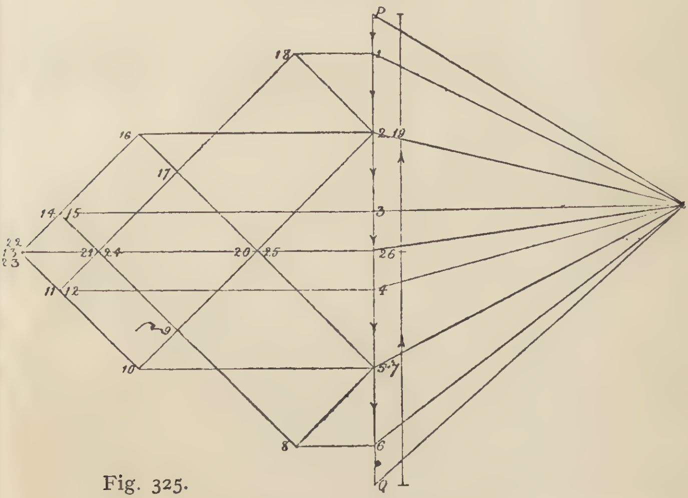


Fig. 325.

TABLE OF STRESSES.

	Bar.	Ten.	Com.		Bar.	Ten.	Com.
a	14—13	...	14·14	*f*	13—22	...	...
	15—22				14—15		
b	16—15	...	28·28		P—19	...	30
	17—21				1—18	...	20
c	18—17	...	42·42		20—26	30	...
	19—20				2—16	...	60
d	17—20	28·28	...		21—26	70	...
	18—19				3—14	...	80
e	15—21	14·14	...		22—26	90	...
	16—17						

transmitted, which is vertical, to the supports by Q 7 and P 19 will be 30 tons respectively. The stress diagram can now be completed by drawing the reciprocal lines in figure 325 of the bars of figure 324, commencing from point 19 of force polygon, and should form a closed polygon by the last stresses 8—7, and Q 7 coinciding with the point 7 of the force polygon.

Figure 324 is the frame polygon; P 1, 2, 3, 4, 5, 6, Q 26, is the force polygon. Lines from O to P 1, 2, 3, 4, 5, 6, Q 26, are the polar lines. Figure 324 is the polar polygon; 1—18, 18—19, 19—20, 20—26, etc., figure 325, is the stress diagram.

The stress diagram, if measured with the same unit as the force polygon, will give the stresses on each bar, which on comparison will be found to give the same result as that obtained by algebraic methods in the chapter on Girders.

Vertical members immediately beneath the load and joining the apices of inclined bars may be considered as dividing and distributing the load equally on the two booms, and for the purposes of calculation may be taken as such. These problems would after this operation be solved in a similar manner to the previous example.

Roof and other trusses must be designed to support and resist dead and live loads. Usually the weight of the covering and the truss constitutes the former, and the pressure of the wind the latter.

TABLE GIVING WEIGHT OF ROOF MATERIALS.

(*From Hurst.*)

	lbs. per foot super.
Common rafters and purlins (wood trusses)	7
,, ,, ,, (iron trusses)	6
One-inch deal boarding	3·33
Battens 3 × ¾ laid 8½ in. gauge	1·32
Asphalted felt	0·5
Zinc, laid with rolls, 12 in. gauge	1·5
,, ,, ,, 14 in. gauge	1·7
,, ,, ,, 16 in. gauge	1·9
Lead and copper, according to weight per foot, adding one-tenth for seams and laps.	

Weight of Roof Materials—*continued.*	lbs. per foot super.
Corrugated iron, 20 BW gauge, with 5 in. corrugations (measured over all)	1·90
,, 18 ,, ,, ,, ...	2·60
Slates, 3 in. lap, all sizes, except Rags or Queens, including nails	9·0
Rags and Queens, including nails	12·0
Tiles, plain, 10½ in. × 6 in. × ½ in., including mortar for pointing, 4 in. gauge	16·0
Ceiling, including joists, 10 feet bearing and lath and plaster	12·0
Snow, according to climate	3 to 10·0

Combined Load.—It is usual to measure the area of the slope of the roof in feet from centre to centre of adjoining bays, and multiply it by the weight per super foot of the dead load, and to this must be added the normal wind pressure per square foot to find the value of the sum of the dead load and wind pressure. The horizontal values of wind pressure are given in the article on the stability of walls, and it is sufficient to note that for ordinary practice the wind may be considered to exert a force not exceeding 50 lbs. per square foot on a surface perpendicular to its direction, and to obtain the normal pressure per square foot (Pn) on slope of roof, this must be multiplied by a factor which varies for each inclination. This table is the result of numerous experiments.

TABLE SHOWING THE VALUES of Pn when $P = 1$ lb. per Square Foot. (*From Hurst.*)

Inclination of Surface — i.	Pn Normal to Surface.	Inclination of Surface — i.	Pn Normal to Surface.
Degrees.	lbs.	Degrees.	lbs.
5	·130	50	·952
10	·240	55	·968
15	·349	60	·980
20	·456	65	·987
25	·549	70	·993
27	·603	75	·996
30	·662	80	·998
35	·754	85	·999
40	·834	90	1·000
45	·900		

It must be noticed that the wind acts only on one side of a roof at a time, and therefore the resultant of wind and dead loads has to be determined on one side of the roof with only the dead load acting on the other at the same time.

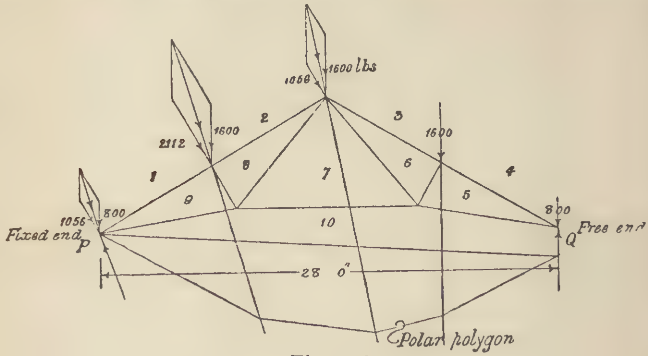


Fig. 326.

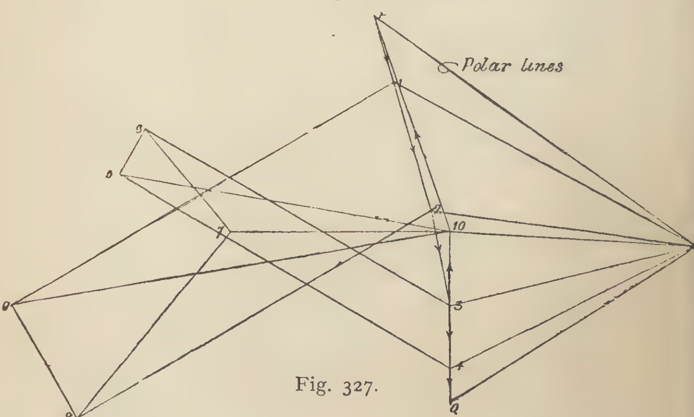


Fig. 327.

It may be necessary in some roofs not symmetrical to determine the stresses when the wind is acting on one side, and then again when it is blowing on the other; but for symmetrically designed roofs it is only necessary to obtain maximum stresses, for one side to be tested and for trusses

both ends of which are fixed, or for trusses fixed on one end and free at the other, it may be shown that the wind acting on the side of roof with sloping reaction gives the greatest stresses.

Timber trusses are usually fixed at both extremities, the expansion and shrinkage of timber in the direction of its length being so small that it may be neglected, in which case reactions will be parallel; these reactions will be—if all the pressures are vertical and if any are sloping—vertical and sloping respectively.

EXAMPLE IV.—Determine the stresses on an iron roof truss of the outline given in figure 326 of 28 feet span and trusses 8 feet apart, slope of rafter 30°, the dead load being equal to 25 lbs. per square foot on the slope, and the wind pressure being 50 lbs. per square foot on a surface perpendicular to its direction.

The number of bays between the fixed points of the principal rafters of trusses is four:—

$\therefore$ Dead load $= W \times \text{area} = 25 \times 16 \times 8 \times 2 = 6{,}400$ lbs., and this divided by twice the number of bays $= \frac{6{,}400}{2 \times 4} =$ 800 lbs.

The rafters may then be considered to carry 800 lbs., and 1,600 lbs. at each of the tie ends and at each intermediate fixed point respectively, as shown in figure 326.

Normal wind pressure on slope = horizontal wind pressure × factor, and using the table given $= 50 \times {\cdot}662 = 33{\cdot}1$ lbs. per foot of area on slope, say 33 lbs.

Normal wind pressure on roof $= P_n \times \text{area} = 33 \times 16 \times 8 = 4{,}224$, and this divided by twice the number of bays acted on $= \frac{4{,}224}{4} = 1{,}056$ lbs. The extremities of rafters may, for all practical purposes, be considered to be acted upon by 1,056 lbs., and the intermediate fixed point by $2 \times 1{,}056 = 2{,}112$ lbs.

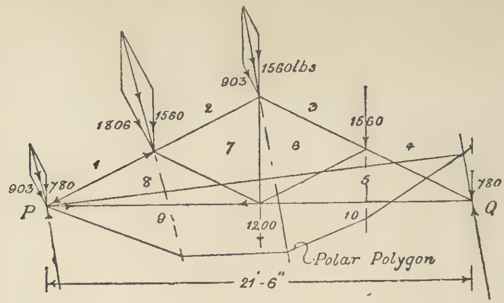


Fig. 328.

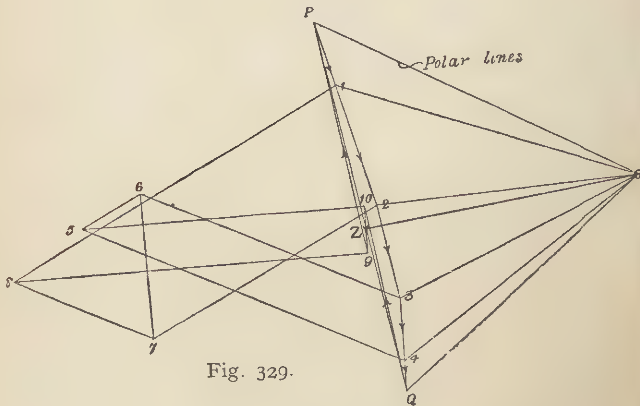


Fig. 329.

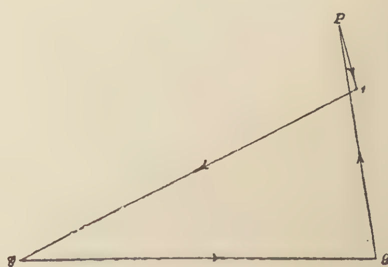


Fig. 330.

The resultant of vertical and sloping pressures is found as shown in figure 326, and then the problem may be solved by applying the working of the eight operations already given in this chapter. One point extra it is necessary to notice, and that is, in problems with sloping reactions, the polar polygon must be commenced at the wind-pressed and fixed side of frame polygon, which, as already stated, will give the maximum stresses and are the sides having the sloping reaction in figures 326 and 327.

EXAMPLE V.—Determine the stress on the members of a king-post roof truss of 21 feet 6 inches span, $\frac{1}{4}$ pitch, and trusses 10 feet apart. The dead load is 26 lbs. per foot super, measured on slope, and to resist a horizontal wind pressure of 50 lbs. per square foot.

The dead load will be found by working, as in previous example, to be 780 lbs. and 1,560 lbs. at each tie end, and at each intermediate fixed point of the rafters respectively.

The wind pressure will be $50 \times \cdot 603 = 30 \cdot 15$ lbs. per square foot, say 30 lbs., and, working as in previous example, will be 903 lbs. and 1,806 lbs. at each end, and at the intermediate fixed point of the principal rafter.

The ceiling load = W × area, and using the table given $= 12 \times 20 \times 10 = 2{,}400$ and this divided by twice the number of bays on tie-beam $= \frac{2{,}400}{4} = 600$ lbs. Therefore, 600 lbs. and 1,200 lbs. may be considered to be supported by the walls, and at the central fixed point of the tie-beam respectively. The two vertical loads of 600 lbs., considered in this case to be carried by the walls directly, need not be, and are not here taken into account as affecting the stress diagram; but it must not be forgotten that the total stress on the abutments will be the value of P 9, or Q 10, figure 329, plus in each case the vertical load of 600 lbs. which is here dismissed.

The order of the eight operations should be followed

and worked. The only point in which this example differs from the preceding in working, is in the determination of the reactions due to having ceiling loads.

In determining the reactions in this and similar cases, it will very much simplify the working, and it is convenient to first find the reactions as if there were no ceiling loads, these will be found to be Q Z and Z P; the force polygon has now therefore the angular points P 1, 2, 3, 4, Q Z.

The effect of the 1,200 lbs. supported at the centre of the tie-beam is to increase the reactions P 9 and Q 10 by a vertical load of 600 lbs. each. At the point Z in the force polygon draw a vertical line, making Z 10 and Z 9 each equal to 600 units; join Q 10 and P 9, and the required force polygon is now complete.

Figure 328 gives the frame and polar polygons.

Figure 329 shows polar lines, force polygons, and stress diagram.

Figure 330 shows how the sense of the stresses of all members in a truss may be obtained, by starting with the forces and bars forming a nucleus and containing a reaction and drawing the reciprocal polygon; it will be readily seen that the reciprocal polygon is only a part of the reciprocal polygon of all the forces, and in this case the four lines forming the reciprocal polygon of the nucleus, figure 330, may be readily traced in figure 329.

Secondary Trusses.—In some cases it may be convenient to break a complicated truss into primary and secondary trusses, treating the supporting joints of the primary trusses first as fixed abutments, and then taking the reactions P_2 and Q_2 of the secondary trusses as loads carried by the primary trusses.

The application of the principles of graphic statics to the type of truss known as the Belgian Roof truss is shown in figures 331 to 334. For convenience in determining the

Fig. 331.

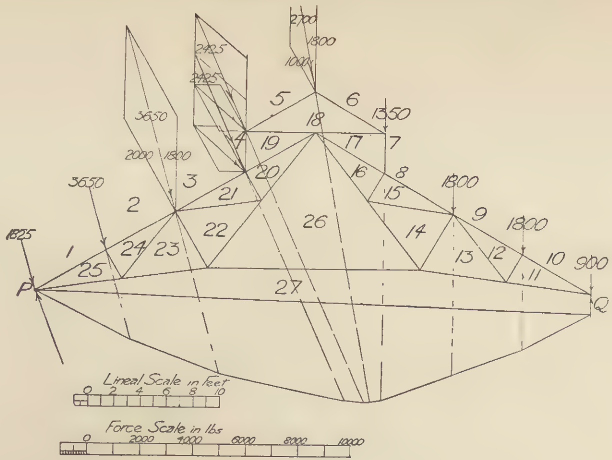
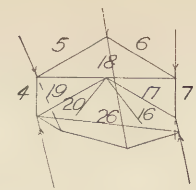


Fig. 332.



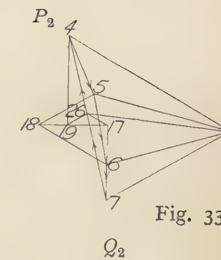
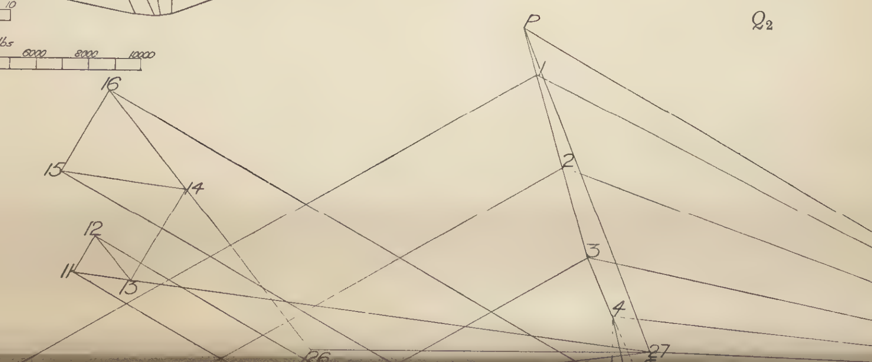


Fig. 333.



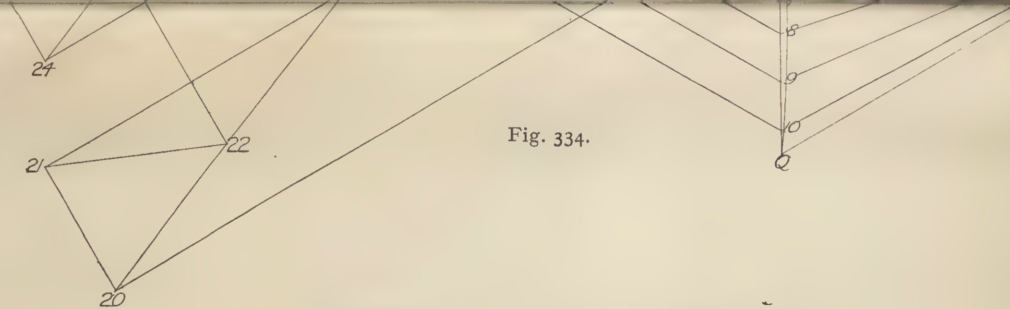


Fig. 334.

Bar	Stress in lbs.	Nature	Required Sectional Area	Proposed Section	Bar.	Stress in lbs.	Nature	Required Sectional Area.	Proposed Section
1-25	29050	+	2·73	4"×5"×½" T	25-27	30000	—	2"	1⅝ ○
10-11	25350	+	—	"	11-27	22100	—	—	—
2-21	28150	+	—	"	23-27	25150	—	1·12	1⅝ ○
9-12	24450	+	—	"	13-27	20000	—	—	—
3-21	29350	+	—	"	26-27	12850	—	·86	1⅛ ○
8-15	25900	+	—	"	22-26	13000	—	—	—
19-20	28200	+	—	"	14-26	7800	—	—	—
7-16	23000	+	—	"	20-26	19850	—	1·323	1⅜ ○
4-19	3350	+	—	4"×4"×½" T	16-26	12600	—	—	—
17-7	2850	+	—	"	24-23	4750	—	·317	⅞ ○
5-18	2300	+	—	"	12-13	2200	—	—	—
6-18	2800	+	—	"	21-22	6900	—	·46	⅞ ○
25-24	3600	+	—	2½"×2¾"×⅜" T	15-14	4750	—	—	—
11-12	1550	+	—	"	18-19	1000	—	·77	½ ○
23-22	7950	+	·86	2½"×2¾"×⅜" T	18-17	2550	—	—	—
14-13	4150	+	—	"			—	—	—
21-20	5300	+	—	2½"×2¾"×⅜" T			—	—	—
15-16	3600	+	—	"			—	—	—

[*Between pages* 420 *and* 421.

stresses, the upper or lantern portion is worked separately, thus breaking a comparatively complicated truss into two trusses. The stresses under the given loads in the secondary truss are shown in figure 333, the reactions $P_2 - 26$ and $Q_2 - 26$ are then taken and added to the wind and dead loads upon the primary truss, as shown in the frame polygon, figure 331.

In steel or iron roofs it is usual to fix the truss on one side only, and on the other to support the end of the truss upon rollers or other contrivances that will permit of freedom to expand and contract, the weight of the roof in most instances being sufficient to prevent any upward movement through wind pressure.

The parallels to polar lines P and Q, if produced till they meet, give one point in the pathway of the imaginary resultant of all the external forces, then a parallel to P Q of the force polygon drawn through this point will indicate its direction, which is useful to know in many problems in which the structure rests upon one support, as in the roofs of many railway platforms, or for the purposes of calculation where there are more than one support. In working out this stress diagram, the joint or node 2, 24, 23, 22, 21, 3 is said to be indeterminate, owing to the forces having to be distributed over five bars instead of four, or less, as in most cases, but this may be determined when it is recognised that parallels to the bars 20—21, 21—22, 20—26, must form an isosceles triangle, the width of the base 20—21 being known and the position of the vertex being on the parallel to bar 23—22, drawn through point 23 of the stress diagram, the position of point being of necessity midway between 21—3, and 20—17, as shown in figure 334.

Figure 331 gives the dead and wind loads in lbs. on the truss 40 feet span, 42 feet 3 inches between centres of bearing pitch 30°, trusses 10 feet apart. The dead load is taken at 30 lbs. per square foot on the slope, and the normal component of the wind pressure as 33 lbs. per square foot.

The table gives the value of the stresses measured from the stress diagram, the required sectional area deduced as shown in the chapter on pillars and girders, and the proposed sections as shown, with all necessary details, figures 776 to 779, in my *Elementary Course.*

Figures 335 and 336 give the dead and wind loads on a truss 50 feet between centres of bearing, trusses 12 feet apart, dead load 30 lbs. per square foot super on slope, normal component of wind pressure 33 lbs. per square foot, ceiling load 12 lbs. per square foot.

The working is similar to that given for the king post roof truss, 21 feet 6 inches span, as shown in figures 328 and 329.

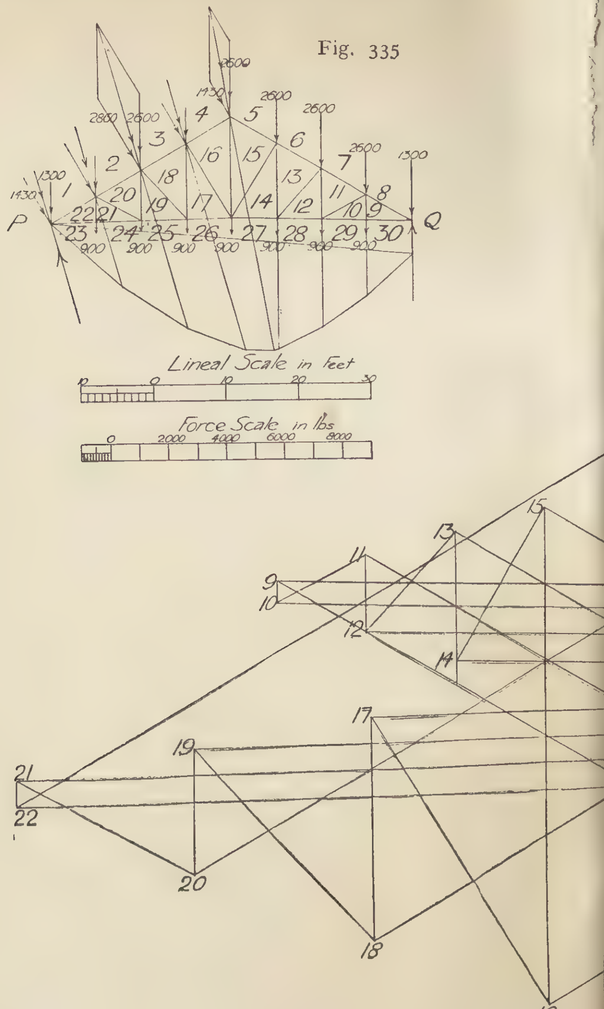
The table gives the value of the stresses on the members, measured from the stress diagram, the required sectional area computed as shown in the chapters on pillars and girders, and the proposed sections as shown, with all necessary details, in figures 740 and 741, *Elementary Course.*

Figures 337 and 338 give an arched rib truss for a span of 40 feet between centres of bearing trusses 15 feet apart, dead load consisting of concrete roof 50 lbs. per square foot of slope, normal component of wind pressure 50 lbs. per square foot. In this roof, as often in roofs of curved form of small span, the trusses are taken as fixed at both ends, hence the reactions are parallel. A table is given in the chapter on roofs with the stresses on the members measured from the diagram, and the calculations are worked to obtain the necessary sectional area and the proposed sections. Figures 780 to 787, *Elementary Course*, give all the necessary drawings and details.

Figures 339 and 340 show the arrangement of the outline for computation purposes of a mansard roof truss of steel members. In this system the bars 9—10, 7—10, 5—10, 8.7.6—9.10.5. are displaced by gusset pieces, which do the work of those bars and consequently resist the stresses. The stresses on the members are measured from the

Truss for Supporting Ceiling—50 ft. Span.

Fig. 335



Stress	Nature	Required Sectional Area	Proposed Section	Bar	Stress	Nature	Required Sectional Area.	Proposed Section
56825	+	3·8	4×3×½ T	17-26	24750	—	—	4×3×½ T
52200	+	—	"	14-27	21700	—	—	"
51500	+	—	"	22-21	925	—	·061	2¼×½ bar
8700	+	—	"	10-9.	750	—	—	"
6100	+	—	"	20-19	4250	—	·283	2¼×½ bar
5100	+	—	"	11-12	2650	—	—	"
0600	+	—	"	18-17	7675	—	·512	2¼×½ bar
1375	+	—	"	13-14	4450	—	—	"
7000	—	2·47	4×3×½ T	21-20	6900	+	—	3×3×½ T
7900	—		"	10-11	3475	+	—	"
6950	—	—	"	19-18	9050	+	—	"
7850	—	—	"	12-13	4650	+	—	"
0850	—	—	"	17-16	11800	+	2·48	3×3×½ T
4875	—	—	"	14-15	6150	+	—	"
7200	—	1·15	3½×½ Bar					

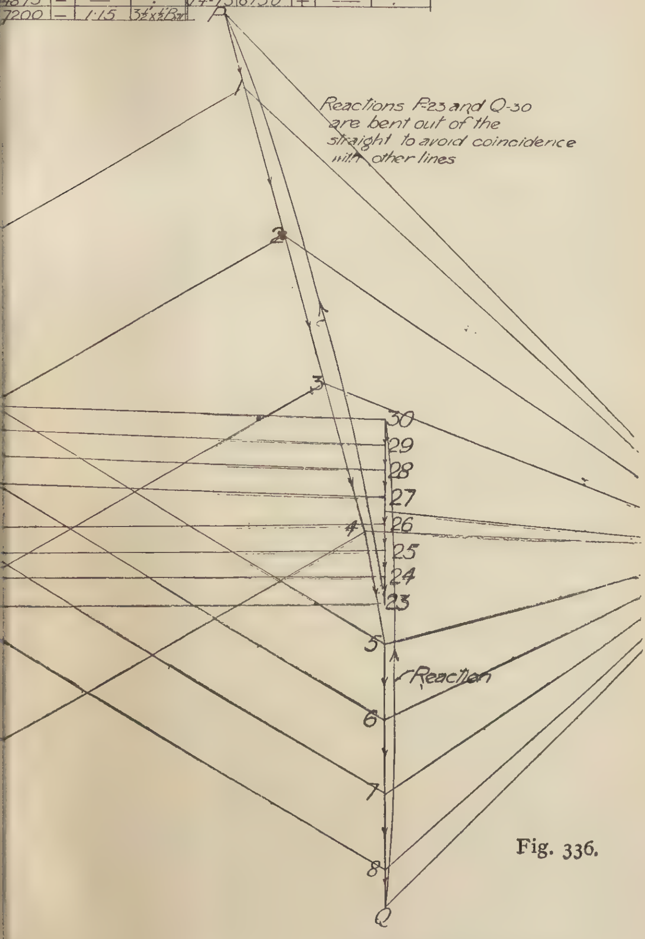


Fig. 336.

[*Between pages 422 and 423.*

ARCHED RIB TRUSS—40 FT. SPAN.

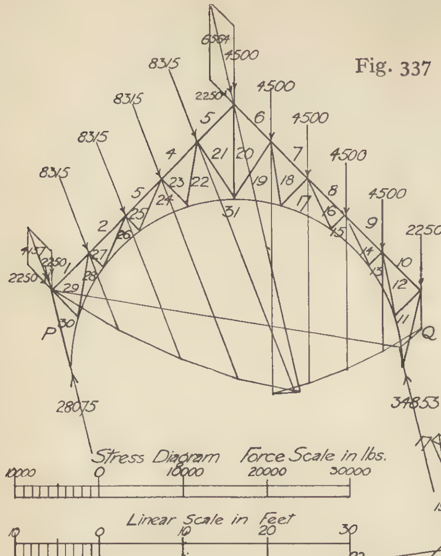


Fig. 337

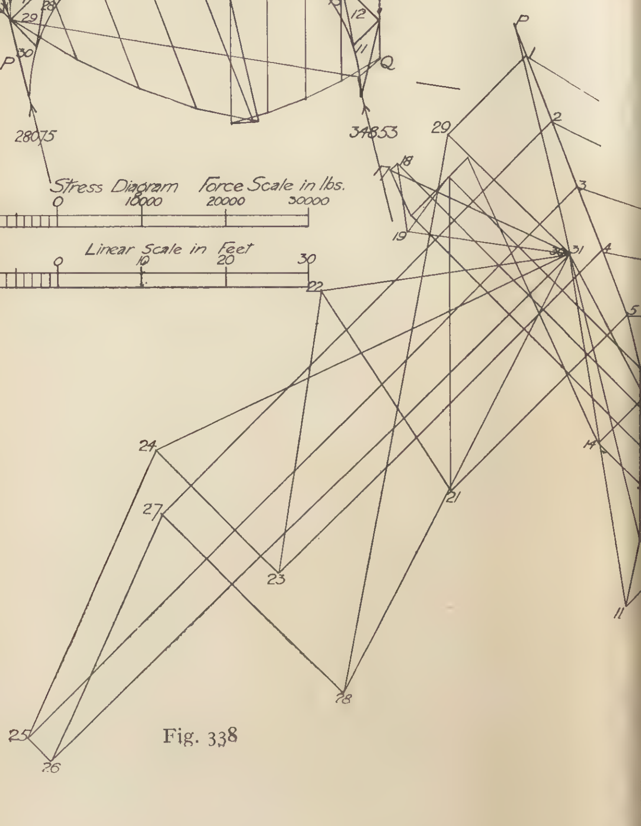


Fig. 338

Mansard Roof Truss—30 ft. Span.

Fig. 339.

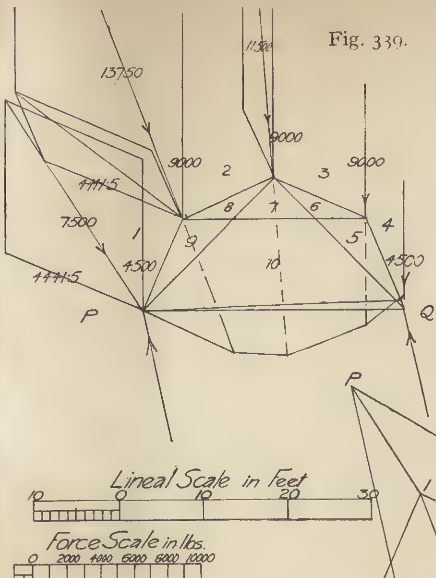
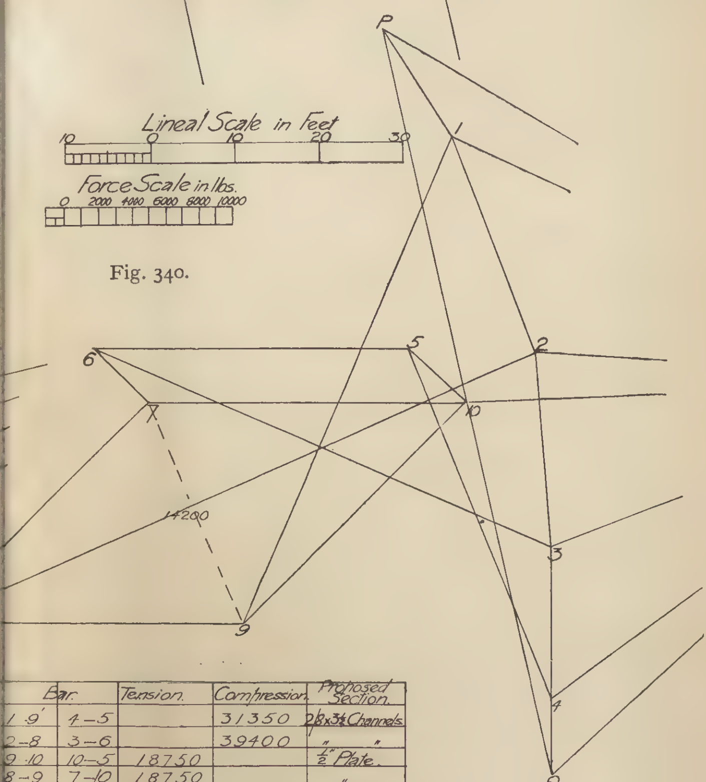


Fig. 340.



Bar.		Tension.	Compression.	Proposed Section.
1·9′	4–5		31350	2 8x3½ Channels
2–8	3–6		39400	" "
9·10	10–5	18750		½" Plate.
8–9	7–10	18750		"
	6·5	18750		"

[*Between pages 422 and 423.*

diagram and the proposed sections given in the table attached, and the calculations are given in the chapter on roofs. Figures 788 to 793, *Elementary Course*, give all the necessary drawings of the truss.

Centre of Area of Irregular Figures.—Inspect the given figure, and, where possible, draw a line Z Z, as in figure 341, such that the area on each side is symmetrical; then divide Z Z into a number of equal parts, the greater the number

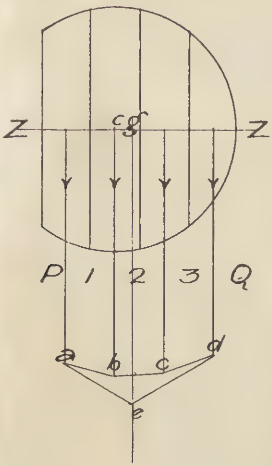


Fig. 341.

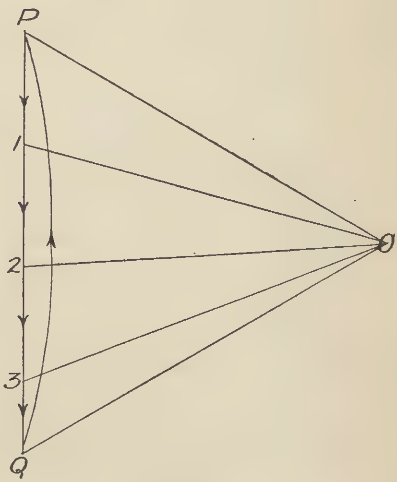


Fig. 342.

the more accurate will be the result. From these points draw lines perpendicular to Z Z, cutting the figure into a number of segments, all of equal width. Let each width be bisected, and lines drawn through these bisecting points and perpendicular to Z Z, then the areas of each strip will be (without any appreciable error) proportionate to these median lines. The given figure 341 is divided into four equal strips, and P—1, 1—2, 2—3, and 3—Q are the median lines, and represent proportionately the area of each strip. By treating

these similarly to forces perpendicular to $Z\ Z$, and by using the operations already described, comprising force polygon, polar lines, and drawing the polar polygon *a b c d e*, the point *e* will have been determined, which is a point in the pathway

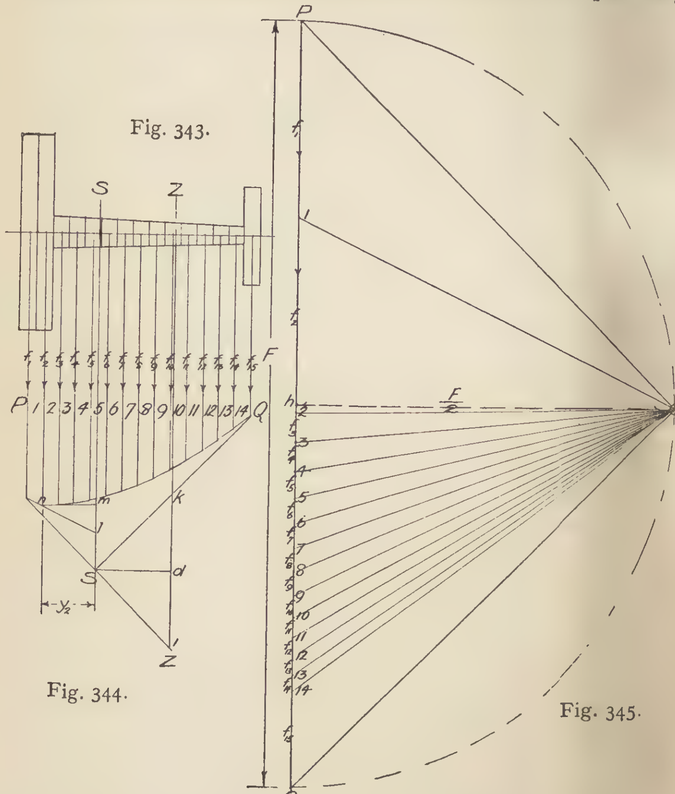


Fig. 343.

Fig. 344.

Fig. 345.

of the resultant of that system of parallel forces, and this resultant produced will cut the line $Z\ Z$ in g; this will be the centre of gravity or centre of area of this figure, for it is obvious the centre of gravity must be on the line $Z\ Z$, as the figure is symmetrical about it, and g is the intersection

of the resultant with $Z\,Z$, when the areas have been represented by parallel forces with the given direction. Should the figure not be symmetrical about the given line $Z\,Z$, then must the figure have another line drawn across it as $Z_2\,Z_2$, making any convenient angle with $Z\,Z$, and similar working applied to determine the pathway of a new resultant force; where this latter intersects the first resultant will give the *c g* or centre of area required.

Moment of Inertia.—The numerical value of the moment of inertia of any section is given as the sum of the products of all the particles into the squares of their distances from any assigned axis, and if the assigned axis passes through its centre of gravity it has been shown to give its minimum value. If it passes through any other point, then it is the sum of the value about its centre of gravity plus the square of the perpendicular distance of the assigned axis from the centre of gravity into its mass, which latter may be represented by the area of its section.

Graphically the value of the moment of inertia termed I about the centre of gravity may be shown to be the value of the area of a certain funicular polygon termed F_1 into the value of the area of its section termed F—

$$\therefore\ I = F\,F_1.$$

Draw given section, figure 343, and determine axis S S passing through the centre of gravity determined as already shown. Next draw force polygon and make polar distance $oh = \frac{F}{2}$ where F is the sum of the median lines (f) or a line equal to the area of the given section. Draw polar or funicular polygon in the usual way, and determine S S passing through centre of gravity of the section. Where force line f_2 intersects polar polygon in n continue the adjacent sides to cut the line S S in m and l. Let the perpendicular

distance of f_2 from S S be termed y_2, then using figures 343 to 345—

$$\frac{m\,l}{y_2} = \frac{1-2}{o\,h}$$

$$\text{but } 1-2 = f_2 \text{ and } o\,h = \frac{F}{2}$$

$$\therefore \frac{m\,l}{y_2} = \frac{f_2}{\frac{F}{2}} = \frac{2\,f_2}{F}$$

$$\therefore \frac{m\,l}{2\,y_2} = \frac{f_2}{F}$$

$$\therefore \frac{m\,l\,y_2}{2} = \frac{f_2\,y_2^2}{F}$$

that is, area of $\triangle\, l\,m\,n = \dfrac{f_2 \text{ into the square of its distance from assigned axis.}}{\text{area of the given section}}$

$\therefore$ as funicular polygon is composed of the sum of such triangles as $l\,m\,n$

$$F_1 = \frac{1}{F}\Sigma\,(f\,y^2)$$

$$\text{but } I = \Sigma\,(f\,y^2) = F\,F_1 \text{ about S S}\delta_1.$$

The area of the polar polygon may be obtained by finding its equivalent triangle. Multiplying this area by the value of F will give the value of I.

The moment of inertia I_1 about any assigned axis $Z\,Z$ will be, using the diagram—

$$I_1 = F\,(F_1 + F_2)$$

where F_2 = area of the triangle $i\,k$ S

$$\frac{i\,k}{d\,S} = \frac{F}{\frac{F}{2}}$$

$$i\,k = 2 \cdot d\,S$$

and the area of the triangle $i\,k$ S $= (d\,\text{S})^2$.

CHAPTER IX.

GIRDERS.

Calculation of Girders. — The calculations of girders determining their ultimate resistances may be found by the rational as well as by the empirical formulæ: (α) the rational is based upon reasoning, taking as axioms laws which are reasoned out in works upon Theoretical Mechanics; whilst (β) the empirical is the application of analogy to the value of a given experimental result.

The former (α) is generally used, whilst the latter (β) is chiefly restricted to rectangular sections under central or distributed loads.

The rational formulæ, the proof of which may be found in works on Applied Mechanics, is as follows:—

The moment of the load must equal the moment of resistance of the material at the instant of breaking; and if M represent the moment, L the load say in lbs., and R the ultimate resistance of the material in lbs. per square inch of section, then $ML = MR$.

The value of the moment of the load varies according to the position of the load and the method of fixing the girders, and may be deduced for all cases from the following:—

(γ) The algebraical sum of forces if parallel and acting upon a beam in equilibrium equals zero.

(δ) The algebraical sum of the moments of the loads, whether parallel or not, if the beam be in equilibrium equals zero.

Equations (γ) and (δ) are useful for determining any two unknown reactions of girders, when the positions of the forces are given (which is usually done in practice), and the bending moment at any point x may be determined by finding the algebraical sum of the moment of the forces on the right or left of the plane perpendicular to the beam containing the point x.

An example will illustrate this :—

A beam 15 feet between supports is loaded with 15 cwts. at A, a point 5 feet from C, and with 12 cwts. at B, a point 10 feet from C. What proportion of these loads in lbs. will be carried at the supports C and D respectively? and what is the greatest bending moment in inch lbs. in the beam? It is clear by inspection that the forces C and D are parallel, for A and B may be represented by one resultant vertical force; and if three forces in equilibrium are in one plane, they must be either (ϵ) parallel or (ζ) meet in a point, and as the reaction of smooth planes is perpendicular to their surface, the inference is that the reactions may be considered as parallel, then by equation (δ) taking moments at C.

$$\text{Moment of the forces at C} = 0$$
$$\therefore (C \times d) + (A \times d_2) + (B \times d_3) + (D \times d_4) = 0$$

Advantage is taken in this equation to discover the two unknown quantities C and D by choosing a position in which the value of d is zero (the value of C for the present equation is then immaterial), and the direction of each force is given by the plus or minus sign (the direction of the hands of a watch being assumed as plus), then

$$O + (15 \times 112)(5 \times 12) + (12 \times 112)(10 \times 12) - D(15 \times 12) = 0$$
$$100{,}800 + 161{,}280 = 180\,D$$
$$\therefore D = \frac{262{,}080}{180}$$
$$\text{and } D = 1456 \text{ lbs.}$$

Then by equation (γ)

It must be noted the direction determines the sign

$$-C + A + B - D = 0$$
$$\therefore A + B = C + D$$
$$\text{and } 1680 + 1344 = C + 1456$$
$$\therefore C = 1568 \text{ lbs.}$$

It may be useful to note that the greatest bending stress will be immediately beneath one of the loads, and on a beam supported at both ends will be over the opening, therefore in this case at A or B—

Taking moment on left side of A—

$$\begin{aligned}\text{Bending moment} &= C \times \text{distance from A}\\ &= 1{,}568 \times 60\\ &= 94{,}080 \text{ inch lbs.}\end{aligned}$$

Taking moment on right side of B—

$$\begin{aligned}\text{Bending moment} &= D \times \text{distance from B}\\ &= 1{,}456 \times 60\\ &= 87{,}360 \text{ inch lbs.}\end{aligned}$$

therefore the maximum bending moment is at A and is 94,080 inch lbs.

Technical Terms.—The following is an explanation of some of the terms used in iron and steel girder construction :—

Clear Span is the horizontal distance between the abutments.

Effective Span is the distance between the centres of the bearing surfaces of the girder on the supports, and is taken in the event of the camber of the girder preventing the bearing surface of the girder resting fairly on the stone template.

Effective Load is the effective span in feet multiplied by the weight of the distributed load per foot run.

Bearing Surface is that part of the lower face of the girder which, when loaded, rests upon the support. The

bearing area is calculated from the formula $S = P \div f_c$ when S = bearing area ; P = total load; and f = safe resistance per unit area. The length of the bearing area where of stone or brick should never be less than $4\frac{1}{2}$ inches and is often the span $\div$ by 30.

Total Length of the girder is the length to the edge of the bearing surfaces, plus the length of the bearing surfaces.

Depth is the distance between the extreme fibres of the flanges.

Feathers.—These are rounded or triangular fillets inserted at the angles of constructional cast-iron work, usually making angles of 135° with the horizontal and vertical faces ; sharp internal angles in cast iron tend to induce a plane of weakness during the process of cooling.

Camber. — Cast-iron girders should have a camber of $\frac{3}{4}$ inch to every 10 feet of span ; wrought-iron and steel girders $\frac{1}{2}$ inch in 10 feet.

Girder Calculations. — The calculations for determining the maximum section of flanged girders are based upon the theory that "the moment of the load equals the moment of resistance of the material as influenced by its section." If the former be symbolized by ML and the latter by MR, it may be represented thus: $ML = MR$.

The following abbreviations will be used :—

W = distributed load or concentrated load in gravitation units, as lbs., cwts., or tons.

w = distributed load per given unit of length.

L = span in given unit of length = (*a*) distance between supports in a whole beam, (*b*) distance between W and support in a semi-beam or cantilever loaded with W.

A = Area in square inches of flange.

f_o, f_c, f_t, and f_s = Safe working or breaking load for material in tons per square inch of section, in tension or compression, compression, tension or shearing respectively.

D = depth of girder between the extreme fibres of the flanges given in units (*a*)

$= \dfrac{L}{10 \text{ to } 20}$ in a whole beam usually, or (*b*)

$= \dfrac{2L}{10 \text{ to } 20}$ in a semi-beam or cantilever.

= in lattice or open web girders from $\dfrac{L}{6 \text{ to } 10}$

F = width of girder flange (*a*) usually $\dfrac{L}{30 \text{ to } 40}$

(*b*) usually $\dfrac{2L}{30 \text{ to } 40}$

L and D must be in the same lineal unit.

w, W and S in the same gravitation units.

I = moment of inertia.

δ = distance of the extreme fibres from the neutral axis.

r = radius of gyration and is equal to the $\sqrt{\dfrac{I}{A}}$

Where used in any other way explanation will be made.

Moments due to varying Loading and Fixing of Girders.— The following give the values of the maximum bending moments corresponding to different loading and modes of support :—

Beams fixed at one end and loaded at the free end ...	WL
Beams fixed at one end and free at the other, load distributed	$\dfrac{wL^2}{2}$
Beams supported at both ends and loaded on the middle	$\dfrac{WL}{4}$
Beams supported both ends and load distributed ...	$\dfrac{wL^2}{8}$
Beams fixed at both ends and loaded in the middle ...	$\dfrac{WL}{8}$
Beams fixed at both ends and load distributed	$\dfrac{wL^2}{12}$
Beams fixed at one end and supported at the other and loaded in the middle	$\dfrac{3WL}{16}$
Beams fixed at one end and supported at the other and load distributed	$\dfrac{wL^2}{8}$

Figure 346 consists of diagrams giving the relative bending and shearing stresses for the six most usual methods of loading and fixing of beams. The shearing stresses are drawn to a larger scale than the bending.

Vertical Shearing Stresses.—The tendency of a girder to be cut through at right angles to its length by the action of

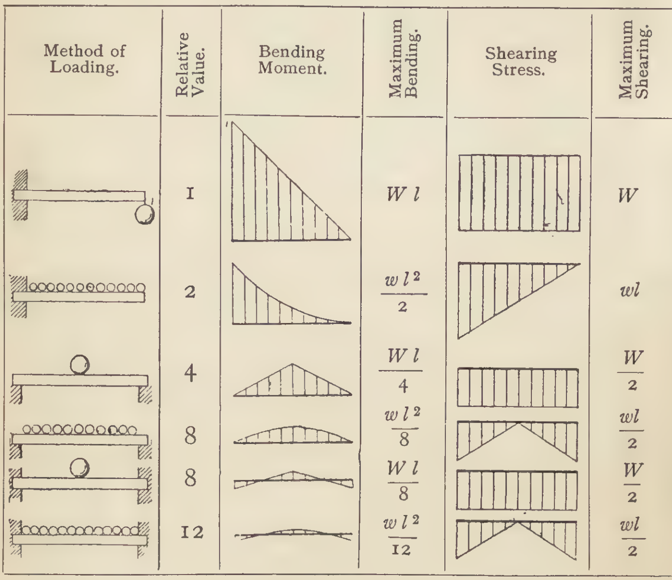


Fig. 346.

the load and resistances of the supports, is equal at any point x in its length, to the difference of the reaction of the support, and the load or sum of the loads between the point x and that support. Figure 346 shows diagrams of shearing stresses for six common cases.

Horizontal Shearing Stresses.—The sum of the horizontal stresses at any section of a girder are equal to the vertical

Fig. 347.

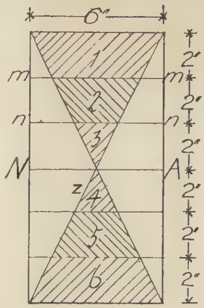
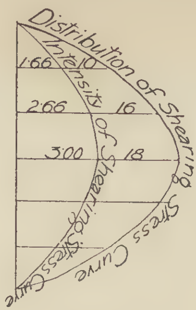


Fig. 348.



shearing stress at that section. The latter are easily determinable, being the reaction at any section, as shown for six typical cases in figure 346. The vertical shearing stress is a couple, and a couple can only be

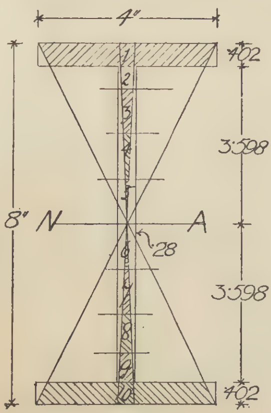


Fig. 349.

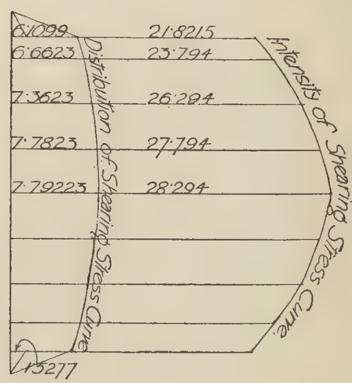
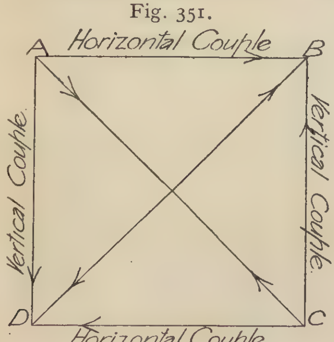


Fig. 350.

Fig. 351.



kept in equilibrium by another couple of equal magnitude.

The vertical shearing stress about any molecule of the vertical cross section of a beam is a couple, and therefore if a molecule is in equilibrium, as a couple can only be kept in equilibrium by another couple, the sum

of the horizontal shearing stresses throughout the depth of the section will form a couple having the moment of the vertical shearing stress.

The distribution of the horizontal shearing stresses will vary from zero at the extreme fibres to the maximum at the neutral axis.

The shaded portion of Figure 347 shows the effective area of the section of a rectangular beam, 6″ × 12″, supposing the fibres to be under a uniform intensity of direct stress.

The horizontal shearing stress at any horizontal layer of section may be represented by ordinates as shown in figure 348, by having a length at *m m* equal to the area of layer one; at *n n* of layers 1 + 2; at N – A of layers 1 + 2 + 3. The distribution curve may be drawn by joining the extremities of these ordinates.

The intensity of shearing stress curve may be obtained by dividing the distribution curve ordinate at any layer by the breadth z of that layer. For rectangular sections the distribution curve will be a parabola and likewise the intensity curve.

$$\text{The area of layer } 1 = \frac{6+4}{2} \times 2 = 10$$

$$\text{,,} \quad \text{,,} \quad 2 = \frac{4+2}{2} \times 2 = 6$$

$$\text{,,} \quad \text{,,} \quad 3 = \frac{2+0}{2} \times 2 = 2$$

The ordinates for distribution curve at $m\ m = 10$, at $n\ n = 10 + 6 = 16$ at $N - A = 10 + 6 + 2 = 18$.

For the intensity curve divide the corresponding ordinates by z or breadth of layer $= \frac{10}{6}, \frac{16}{6}$ and $\frac{18}{6} = 1{\cdot}\dot{6},\ 2{\cdot}6$ and $3{\cdot}0$ respectively as shown in figure 348.

Maximum Intensity of Shearing Stress on Beams of Rectangular Sections.—The following formula will enable to be readily obtained the maximum intensity of shearing stress on beams of rectangular section.

Let R = total shearing stress or resistance to shearing at any vertical section of a rectangular beam

d = depth of section

b = breadth of section

f_s = maximum intensity of shearing stress, *i.e.*, at neutral axis,

then at the neutral axis $f_s\,b = \frac{3\,R}{2\,d}$ $\therefore f_s = \frac{3\,R}{2\,d\,b}$ as the area of a parabola is $\frac{2}{3}$rds of the enclosing rectangle.

Horizontal Shearing Stress Curves—flanged Sections.—Fig. 349 shows a mild steel British Standard Beam 8 in. × 4 in., thickness of web ·28, thickness of flange ·402, with the neutral axis at the centre.

The intensity and distribution curves may be determined as follows :—

From the neutral axis, draw lines to the ends of the extreme layers, also produce thickness of web on extreme layer of flanges, join the extreme points with the neutral axis as shown ; this will give the effective area, supposing the fibres to be under a uniform intensity of stress. Divide the beam into layers 1 to 10. Generally the intensity of pressure of the horizontal shearing stress may be obtained at any layer z by the formula given by Wray—

$$q = \frac{F}{Iz}\int_{y}^{y_1} yz\,dy$$

when F = total vertical shearing stress on any section

I = moment of inertia of that section

z = width of section at any layer of fibres

y = distance of that layer of fibres from N A

y_1 = distance of another layer, farther from N A, but on the same side of it as y.

For the top flange—

$$y_1 = 4\,;\ y = 3{\cdot}598\,;\ z = 4$$

$$\int_{y}^{y_1} yz\,dy = \int_{3\cdot598}^{4} yz\,dy$$

$$= 4\left(\frac{4^2}{2} - \frac{3{\cdot}598^2}{2}\right)$$

$$= 6{\cdot}11$$

For the web—

$$y_1 = 3{\cdot}598\,;\ y_0 = 0\,;\ z = {\cdot}28$$

$$\int_{y_0}^{y_1} yz\,dy = \int_0^{3{\cdot}598} yz\,dy$$

$$= {\cdot}28\left(\frac{3{\cdot}598^2}{2}\right)$$

$$= 1{\cdot}8123$$

Hence at N A, $q = \frac{F}{Iz}\left(6{\cdot}11 + 1{\cdot}8123\right) = \frac{F}{I} \times \frac{7{\cdot}9223}{{\cdot}28} = \frac{F}{I} \times 28{\cdot}294$

At 1 in. above N A, q is less by

$$\frac{F}{Iz}\int_0^1 yz\,dy = \frac{F}{I} \times \frac{1^2}{2} = \frac{F}{I} \times \frac{1}{2},$$

At 2 in. $= \frac{F}{I} \times \frac{2^2}{2} = \frac{F}{I} \times 2$

At 3 in. $= \frac{F}{I} \times \frac{3^2}{2} = \frac{F}{I} \times 4{\cdot}5$

At $3{\cdot}598$ $= \frac{F}{I} \times \frac{3{\cdot}598^2}{2} = \frac{F}{I} \times 6{\cdot}4725$

At any infinitely small distance above $3{\cdot}598$, z changes from ·28 to 4; $\therefore$ $21{\cdot}8215 \div 14{\cdot}283 = 1{\cdot}5277$; therefore the ordinates of intensity curve measuring at the layers starting from the neutral axis are 28·294; 27·794; 26·294; 23·794; 21·8215; 1·5277, as shown in figure 350.

The ordinates of the distribution curve are obtained by multiplying the corresponding ordinates of the intensity curve by z or by the breadth of the section at that layer.

The distribution of the shearing stress throughout the section of beams of small section is often considered unnecessary. The shearing stress is usually taken as if it were uniformly distributed over the whole of the vertical section, but in beams of large section the more exact method should be applied.

f_o A D Proof.—In the equation of moments of flanged girders, the moment of resistance (MR) is taken to be the product of the area (A) of a flange multiplied by the safe load per unit of section (f_o), multiplied by the depth (D);

it is therefore necessary to know how to solve the identity $MR = f_o AD$.

The value of MR is the value of the constant, which varies with the strength of the material multiplied by the moment of inertia divided by the distance of the extreme fibres from the neutral axis.

The moment of inertia is the sum of the product of all the particles forming the section multiplied by the square of their distances from the neutral axis. Let the distance of the extreme fibres δ, of either flange from the neutral axis be made $\frac{D}{2}$.

Let the areas of each flange multiplied by the constant for the stress under which it is subjected equate each other; The flanges being relatively thin, f_c and f_t having equal values, the radius of gyration may be taken without any great error as equal to the depth ÷ by two; the value of the moment of inertia of the web being ignored, then :—

$$MR = \frac{f_o I}{\delta}$$

let A = area of each flange

$$\text{then } MR = \frac{f_o \, 2 \, A \, r^2}{\delta}$$

$$MR = \frac{f_o \, 2 \, A \left(\frac{D}{2}\right)^2}{\frac{D}{2}}$$

$$= f_o \, AD$$

$$\therefore ML = MR = f_o \, AD$$

Resolution of Shearing Couples into Tension and Compressional Stresses on Braces.—The vertical shearing stress couple may be considered as kept in equilibrium by the horizontal shearing stress couple as illustrated in figure 351. A horizontal and a vertical component AB and CB may be considered to have a resultant DB, and likewise AD and CD may be considered to have a resultant BD; these resultants will be equal in magnitude and opposite in direction, and therefore if a bar BD be considered to take

the combined stresses of these two couples, it will be under a tensional stress; in a similar manner AB, AD and CB, CD may be resolved and the combination of the stresses will give a compressional stress on the bar AC.

Cast-iron Girders.—The following articles show how the flanged and small sections of cast-iron, and wrought-iron, girders, may be calculated. Steel girders would now be computed as shown on page 443.

Figures 352 to 354 give working drawings of a cast-iron girder designed to carry a distributed load of 25 tons safely over a clear span of 16 feet, as in the case of a bressumer carrying a brick wall.

The required girder is to carry safely 25 tons, and to this must be added its own weight; to determine this, it is wise to make a preliminary calculation to obtain approximate weight of girder.

Preliminary Calculations.—The object of preliminary calculations is to obtain the approximate weight of the girder; this weight has to be added to the supported load. In calculating for small girders an approximate weight is usually assumed, but to make the working complete it is here not omitted.

For safe loads take tension $1\frac{1}{2}$, compression 6, shearing 2 tons per square inch of section. Depth of girder 1 foot 6 inches.

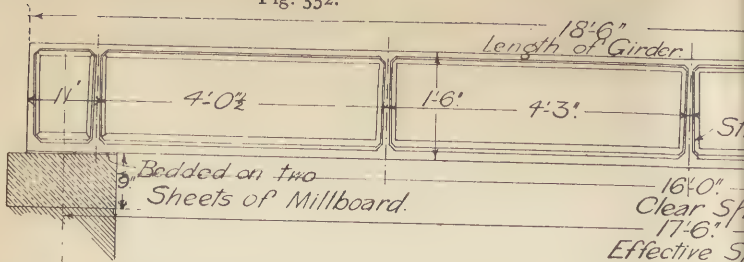
$$\frac{wl^2}{8} = A f_t D$$

$$\frac{\frac{25}{16} \times 16^2}{8 \times 1\cdot5 \times 1\cdot5} = A$$

A = 22·22 area of tension flange, and 22·22 divided by 4 will give 5·55, and this is the required number of inches in area of compressional flange.

Half the load, which is 25 tons divided by 2, is taken by each pier or support, and this quantity is the maximum shearing stress; therefore 12·5 divided by 2 will give 6·25, which is the required sectional area in inches of the web; but to obtain a good casting the web must necessarily contain a much greater area.

Fig. 352.



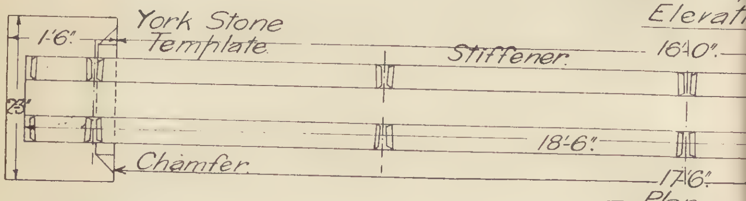


Fig. 353.

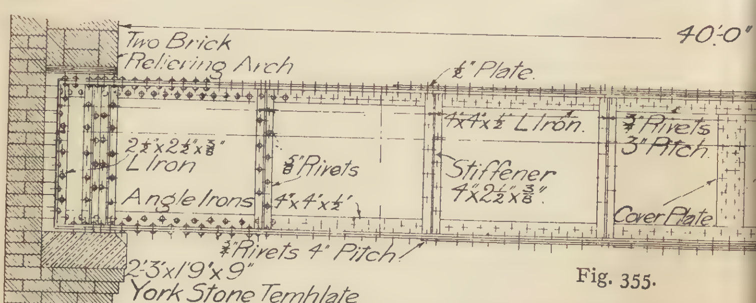


Fig. 355.

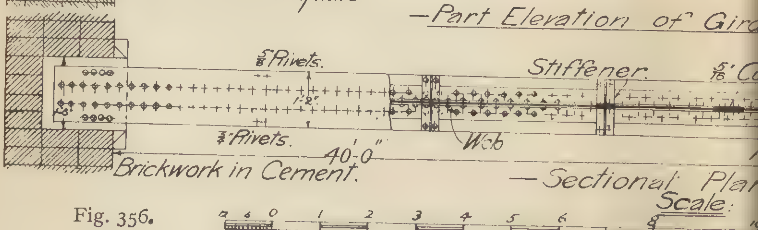


Fig. 356.

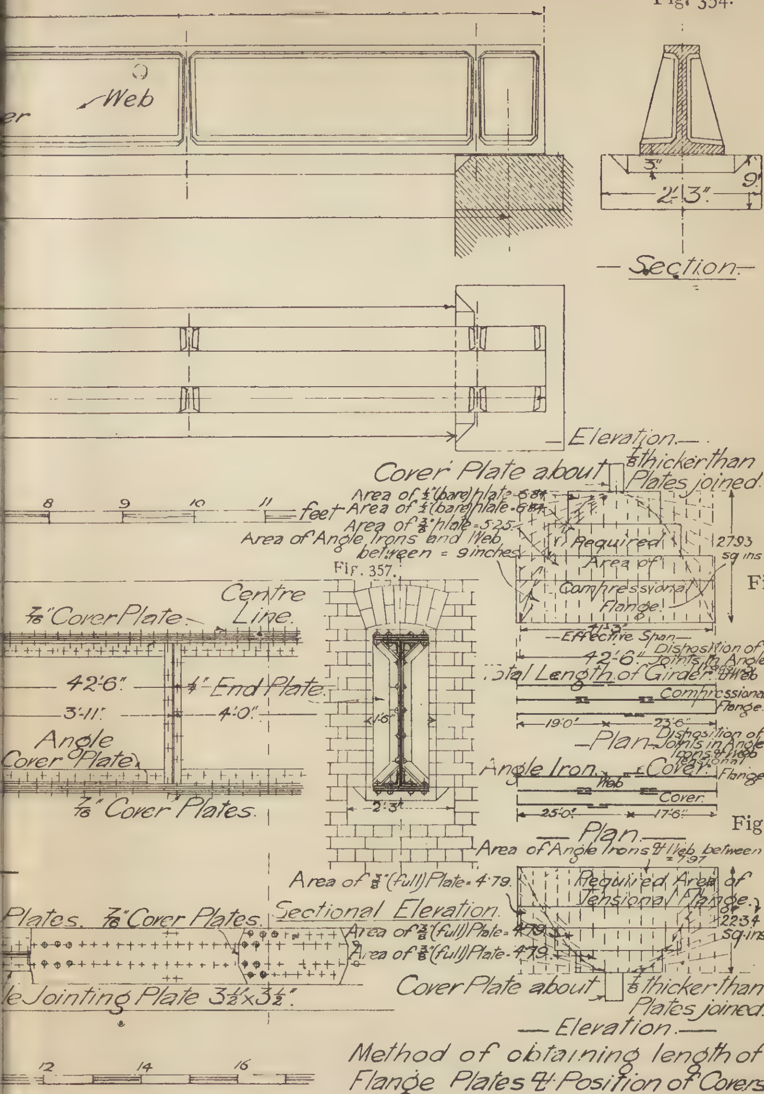


Fig. 354.

Fig. 358.

Fig. 359.

352—359.

[*Between pages 438 and 439.*

Let girder rest 12 inches on a stone template that is chamfered 3 inches back from face of support. Length of girder will then equal 16 feet + 6 inches + 2 feet = 18 feet 6 inches long. From the above calculations find the weight by ascertaining its cubic contents by multiplying its sectional area by length and the weight per cubic foot, adding for stiffeners.

Final Calculations.—Having determined weight, make an allowance for its own weight to be carried, and for the increased sectional area required for the difference of moment of effective span over clear span. Assume final weight of girder over effective span to be 1·5 tons. Effective span equals clear span + 2 chamfers + length of one bearing surface = 16 feet + 6 inches + 1 foot = 17 feet 6 inches. Effective load = 25 tons + (2 × ·75 × 1·6 tons nearly, the load per foot run) + 1·5 tons weight of girder = 25 + 2·4 + 1·5 = 28·9 tons.

$$\frac{wl^2}{8} = A f_0 D$$

$$A = \frac{wl^2}{8 f_0 D}$$

$$A = \frac{28{\cdot}9 \times 17{\cdot}5^2}{17{\cdot}5 \times 8 \times 1{\cdot}5 \times 1{\cdot}5}$$

A = 28·05 square inches required in tensional flange, and 28·05 divided by 4 gives 7 square inches in compressional flange, and 28·9 divided by 2 gives 14·45 tons on support which is the maximum shearing stress, and 14·45 divided by 2 gives 7·2 square inches shearing area required in web.

Weight of Girder.—Length of girder, 18 feet 6 inches.

Section of Girder.	Cubic feet
Tension flange, 1 foot 2 inches × 2 inches average ...	= 3·7
Compression flange, 7 inches × 1 inch average... ...	= ·9
Web tapering iron, $1\frac{1}{4}$ inches to $1\frac{1}{2}$ inches, say average 15 inches × $1\frac{3}{8}$	= 2·6
5 stiffeners on each side and 2 ends.	
15 inches × 11 inches × $1\frac{1}{8}$ average for each stiffener and end	= 0·76
136 feet run of $\frac{3}{4}$ fillet	= 0·26

Total cubic content 8·22 feet, then $8·22 \times 450 =$ total weight in lbs., 3,699 lbs. = 1·6 tons.

Girder Bed.—Area of girder bed determined by the strength of York stone. Stone template to resist crushing safe load being taken as 20 tons per superficial foot. Width of girder flange = 1·16 feet.

Total load = load over entire length of girder + weight of girder = $27·4 + 1·6 = 29·0$ tons, say 30 tons. $30 \div 2 = 15$ on each pier; $15 \div 20 = ·75$ feet area; $·75 \div 1·16 = ·65$ = say, 8 inches for length of bearing.

Stone Template.—Size of stone template determined by strength of brickwork in mortar to resist crushing to 5 tons per superficial foot, then $15 \div 5 = 3$ square feet area required for stone resting on brickwork in mortar.

Width of stone = 1 foot 2 inches + two $6\frac{1}{2}$ inch margins = 2 feet 3 inches.

$3 \div 2·25 = 1·33$ = 1 foot 4 inches depth of stone.

Thickness of stone template equals the width of the stone template minus the width of bearing surface of girder divided by two. The whole of the base of the template will therefore be under direct compression.

Thickness of this stone template—

$$= \frac{2'\ 3'' - 1'\ 2''}{2} = 6\tfrac{1}{2} \text{ inches.}$$

to suit courses of brickwork, say 9 inches.

Wrought-iron Girder.—Figures 355 to 359 give working drawings of a wrought-iron plate girder. The following are the requirements and calculations: A wrought-iron plate girder is required to carry a distributed load of 61 tons safely over a clear span of 40 feet, as in the case of a girder carrying a floor. First determine maximum section. Assume weight of the girder 4 tons.

$$\text{Let depth} = \frac{\text{span}}{12} = \frac{40}{12} = 3·33, \text{ say } 3 \text{ ft.};$$

$$\text{width of flanges} = \frac{40}{35} = 1·11 \text{ ft., say } 1 \text{ ft. } 2 \text{ in.}$$

To ascertain approximate weight make preliminary calculations as worked for cast-iron girder, and determine weight as in final calculations.

Final Calculations.—Assuming weight of girder as 4 tons. Let the length of bearing surface be 1 foot 3 inches.

Effective span = clear span + length of one bearing surface = 40 feet + 1 foot 3 inches = 41 feet 3 inches. Total load = 61 + 4 = 65 tons.

Then for distributed loads

$$\frac{wl^2}{8} = A\, f_0\, D$$

$$A = \frac{wl^2}{8\ SD}$$

$$A = \frac{65}{41{\cdot}25} \times \frac{41{\cdot}25^2}{8 \times 5 \times 3}$$

A = 22·34 net area of tensional flange, and for the net area of compressional flange, substitute 4 as the value of f_c, this will give 27·93 inches.

The total load is 65 tons; this divided by 2 will give 32·5 tons, the load on each support and the maximum shearing stress. Divide 32·5 by the safe shearing stress in tons per square inch, which is 4, and the quotient 8·125 is the required shearing area in web.

Depth of web = depth of girder − 2ce depth of angle iron.
Depth of web = 36 − 2 × 4 = 28 inches.
Thickness of web = 8·125 divided by 28 = ·29 inches.

Let thickness of web, allowing for loss by rusting, be $\frac{3}{8}$ inch.

The net section of the tensional flange under the maximum stress will be the gross section, minus the loss by rivet holes, which may be seen from the drawing to be the rivet holes in angle irons and flange plates.

Area of 4″ × 4″ × $\frac{1}{2}$″ angle iron = (4 + 4 − ·5) × ·5 = 3·75

gross area, deduct one $\frac{3}{4}$ rivet hole $= 3{\cdot}75 - ({\cdot}75 \times {\cdot}5) = 3{\cdot}75 - {\cdot}375 = 3{\cdot}375$ net area, and for two angle irons net area ... ... $= 6{\cdot}75$

Area of web plate between angle iron $= 4 \times \frac{3}{8} = 1{\cdot}5$

$8{\cdot}25$

The required area is $22{\cdot}34$, and $22{\cdot}34 - 8{\cdot}25 = 14{\cdot}09$ inches. The net width of flange $= 14 - 2$ ($\frac{3}{4}$ rivet holes) $= 12{\cdot}5$ inches and $14{\cdot}09$ divided by $12{\cdot}5$ = thickness of tensional flange $= 1{\cdot}13$ inches nearly, say three $\frac{3}{8}$ inch plates.

The gross area of the compressional flange may be calculated to resist the compressional stress, if the rivets fill up the holes thoroughly.

Two angle irons $4'' \times 4'' \times \frac{1}{2}'' = 2 \times 3{\cdot}75 = 7{\cdot}5$ gross area angle irons. Web plate between angle irons $4 \times \frac{3}{8} = 1{\cdot}5$ gross area and $7{\cdot}5 + 1{\cdot}5 = 9$ inches.

Required area $27{\cdot}93$ and $27{\cdot}93 - 9 = 18{\cdot}93$ and this divided by 14 the gross width of flange $= 1{\cdot}35$ inches thickness of flange = two $\frac{1}{2}$ inch plates and one $\frac{3}{8}$ inch plate.

Girder-bearing Surface.—Area of bearing surface of girder determined by the strength of stone template. Taking Bramley Fall safe load 25 tons per foot super.

2)65 tons total load

25)32·5 on each support.

1·3 feet area of bearing surface required by girder on template, and 1·3 feet divided by width of flange $= \frac{1{\cdot}3}{1{\cdot}16}$ $= 1{\cdot}12$ feet length of bearing surface, say 1 foot 3 inches.

Stone Template.—Area of stone template determined by strength of brickwork in cement. Safe load 10 tons per superficial foot. Depth of stone, 1 foot 3 inches + 3 inch margin = 1 foot 6 inches.

0)32·5 load on each support.

1·5)3·25 area required by template on brickwork in cement.

2·16 feet = width of template.

Thickness of Template.—The thickness of the stone template $= \dfrac{\text{width of stone template} - \text{width of bearing surface}}{2}$

$= \dfrac{2'\ 3''-1'\ 2''}{2} = 6\frac{1}{2}$ inches to suit the courses of the brickwork, 9 inches.

Stiffeners, from 3 feet to 4 feet apart, 4 in. $\times\ 2\frac{1}{2} \times \frac{3}{8}$.

Number of stiffeners in girder 24, viz., 12 each side, two end plates each $\frac{1}{4}$ inch thick secured to web by four $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{1}{2}''$ angle irons.

Length of Plates.—The length of plates in flanges may be obtained by drawing a parabolic curve as shown in figures 358 and 359, taking maximum area of each flange as altitude to scale at middle of girder and effective span as base, then on altitude set up area of angle iron, portion of web plate in flange and the area of each plate, the sum of which equals maximum area. From these divisions draw lines parallel to girder intersecting parabolic curve, which will then give the length of each plate.

Mild Steel Rolled Girders.—Examples of the calculations for these are given in the chapter on Foundations, and on Pillars in the example of steel skeleton construction. In the calculations for these—which are printed at the end of this chapter—it is usual to employ the British Standard Sections of Beams; the problem is then to determine the modulus of the section $\left(\frac{I}{\delta}\right)$ deduced from the formula—

$$\text{M L} = \text{M R} = \frac{f_0\, \text{I}}{8}$$

$$\text{M L} = \frac{f_0\, \text{I}}{\delta}$$

$$\frac{\text{I}}{\delta} = \frac{\text{M L}}{f_0}$$

that is the bending moment $\div$ by the safe resistance of the material which is known, gives the modulus of the required

section, then from the B. S. B. select a suitable section that gives the nearest modulus to that required.

Steel Built-up Girders.—For large steel built-up girders it is generally economical to make preliminary calculations as in the case of the cast-iron girder calculations, to determine the weight of the girder to add to the load and the approximate maximum section, then determine the area of the required flanges by the formula $M\ L = f_0\ A\ D$ and determine the area of the web to resist the shearing stress, then make a final computation to determine the value of f_0 for the built-up section from the formula $M\ L = \frac{f_0\ I}{\delta}$ the inertia of the proposed section having to be specially determined, and the section modified if it is found necessary.

Lattice Girders.—Lattice girders consist of a top and a bottom flange or boom, held together by systems of bars, crossing each other in elevation, and riveted to the flanges, and bolted or riveted at the intersection of the bars.

Calculations.—For calculating the stresses on the bars and booms there are two methods in general use—

(α) Graphical. (β) Mathematical.

The graphical method has been shown in the chapter on Statics; the mathematical method will now be illustrated. It is usual to trace the effect of each load on its system of bars, and the algebraical sum of the effects of the loads on each bar of the system will determine the numerical value that it is stressed. It may be noted that the effect of any given load is to cause all braces between load and support pointing downwards and towards the support to be in compression, and all braces inclined upwards from the load in tension.

Vertical members immediately beneath a load and joining the apices of inclined bars may be considered as dividing

and distributing the load equally on the two booms, and for the purpose of calculations is taken as such.

Under a uniformly distributed load all the braces pointing downwards towards the nearest supports are in compression, the remaining inclined braces being in tension.

Take the following as an illustration :—

A span of 60 feet is to be covered by a lattice girder, the depth of which is to be 10 feet, and the lattice bars of which are to be at the usual angle of 45°.

Determine the sectional area required to carry safely, including its own weight, a distributed load of 2 tons per foot, the stress per square inch not to exceed 5 tons.

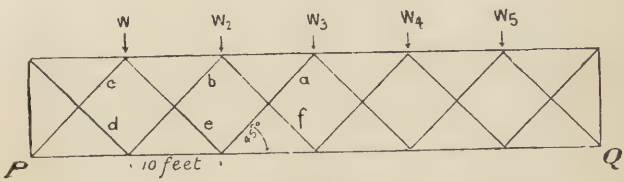


Fig. 360.

Figure 360 is a line diagram of the girder.

Taking into consideration the unsupported part between piers P and Q, there are six bays of 10 feet each; height of girder equal to width of one bay, 10 feet; the load for all practical purposes may be imagined to be collected at the fixed points, viz., at the apices of the lattice bars; then between the extremities each of the five loads is equal to 20 tons, and each of the two end loads will be 10 tons, taken wholly by the end vertical bars, and will not in any way affect the other members of the girder, the total reactions only being increased by the amount.

Number the apices in the compressional flange as 1, 2, 3, 4, 5, at which it will be supposed the distributed load is collected, and will be described as W, W_2, etc.;

and on P's half of girder let the compressional lattice bars be called *a*, *b*, *c*, and the tensional bars *d*, *e*, *f*.

By Newton's third law :—

Reaction at P = 60 tons.
Reaction at Q = 60 tons.

It is sufficient to work out one half of the girder.

(α) The reactions of the supports by the method shown at the beginning of this chapter will each be 60 tons.

(β) The maximum stress on the flanges is found from the formula :—

$$\text{Moment of distributed load} = \frac{wl^2}{8}$$
$$= \frac{2 \times 60 \times 60}{8}$$
$$\therefore A. f_0 D = 900$$
$$\text{and} \therefore A = \frac{900}{S.D.}$$
$$A = \frac{900}{5 \times 10}$$
$$A = 18$$

The next step is to trace these loads from their points of application to the points of support; this will give the amount of vertical load coming upon each lattice bar :—

Bar.	W_1	W_2	W_3	W_4	W_5	Max. tension.	Max. compression.	Uniform load.
a	$-\ 3\frac{1}{3}$		$+\ 10$		$+\ 3\frac{1}{3}$	$3\frac{1}{3}$	$13\frac{1}{3}$	10 compression.
b		$+\ 13\frac{1}{3}$		$+\ 6\frac{2}{3}$			20	20 compression.
c	$+\ 16\frac{2}{3}$		$+\ 10$		$+\ 3\frac{1}{3}$		30	30 compression.
d		$-\ 13\frac{1}{3}$		$-\ 6\frac{2}{3}$		20		20 tension.
e	$+\ 3\frac{1}{3}$		$-\ 10$		$-\ 3\frac{1}{3}$	$13\frac{1}{3}$	$3\frac{1}{3}$	10 tension.
f		$+\ 6\frac{2}{3}$		$-\ 6\frac{2}{3}$		$6\frac{2}{3}$	$6\frac{2}{3}$	$6\frac{2}{3}$ tension or compression.

Having now found the total vertical load upon each of the lattice bars to the left, the next operation is that of

ascertaining the amount of stress produced in each bar by the load.

Rule.—Stress upon any lattice bar equals vertical load multiplied by length of bar, and divided by the depth of girder.

Or, stress equals vertical load, multiplied by the secant of the vertical angle of lattice bar and vertical line representing load.

Or, stress equals vertical load multiplied by the co-secant of the horizontal angle of lattice bar.

If the bars are inclined at 45°, then

$$\text{sec. } 45° = \text{co-sec. } 45° = 1{\cdot}414.$$

If the bars are inclined at 60°, then

$$\text{sec. } 30° = 1{\cdot}15\text{ ; co-sec. } 60° = 1{\cdot}15.$$

It is necessary to draw out the details of the girder to scale in order to decide the exact position of the rivets, and their effect upon the tensional members of the girder, carefully calculating same so as to allow of any necessary adjustment being made.

The following notes may be of use:—

Total load 120 tons, load upon each pier 60 tons, bearing area required on template equals $\frac{60}{20} = 3$ feet as *a minimum*, size of bed plate may be 2 feet × 1 foot 6 inches.

Template $\frac{60}{5} = 12$ feet area required if the brickwork below is built in mortar, and $\frac{60}{10}$ feet area if built in cement. Always make the size of the template such that it will properly bond in with the brickwork.

Referring to the sizes for the girder the following leading points should be carefully noted:—

In the flanges the greatest stress occurs at the centre of span, or immediately under a concentrated load. In the braces the greatest stresses occur towards the points of

support. The increase of load on each brace, reckoning from the centre of span, is some definite proportion of the apex load.

Towards the centre of span some of the bars are in both tension and compression, and the stresses neutralize each other.

Over the piers the area of metal in web must be sufficient to take the shearing stress, which in uniform loading amounts to one-half the total load.

Bow String Girders.—Girders constructed with an arched top flange (or bow, as it is termed) and a horizontal tie or string, the web being formed with braces or plates with stiffeners, the flanges being of uniform section, and the depth of the girder varying as a parabolic curve, are termed bow string girders, and are suitable to support a uniformly distributed load, the curve of the bending stresses of which varies as the ordinates of a parabolic curve, as shown in figure 346. It is, therefore, only necessary to calculate the section at the centre of the girder, as the bending stresses and resistances decrease uniformly towards the supports. The horizontal stresses in the flanges are the same throughout the length of such girders. The bow is usually an arc of a circle, which, provided that the rise be not greater than one-eighth of the span, agrees sufficiently near to the curve of a parabola.

Hog-backed Girders.—Girders with curved upper flanges the depth of which at the centre being usually in practice twice the depth at the ends, are termed hog or saddle-back, but are of doubtful advantage.

Warren Girders.—Girders constructed with bars forming a repetition of equilateral triangles are known as Warren, as shown in figure 361. This construction is simple and economical.

Whipple Murphy Girders.—Girders constructed with two booms, the braces of which are disposed in the form of **N**, as shown in figure 362, and the inclined bars of which are in tension, are known as Whipple Murphy girders, and are specially suited for dead loads symmetrically applied on top or bottom flanges.

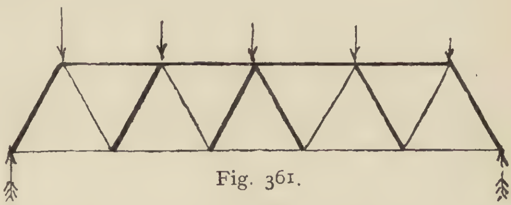


Fig. 361.

Empirical Formulæ.—The strength of a rectangular beam varies directly as the breadth; directly as the square of the depth, and inversely as the length.

If the breadth of a beam is doubled, the strength is doubled, and *vice versâ;* if the depth is increased the strength is increased as the square, from the fact that

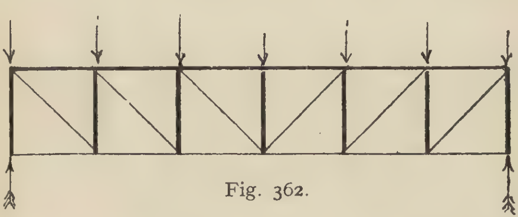


Fig. 362.

increasing the depth not only increases the bulk of the beam, but also the leverage of the fibres which are acting in resistance to the load; other dimensions being the same, the proportionate strengths of beams 7 inches and 9 inches deep are as 49 to 81; the "*greater*" the length of the beam, other dimensions being the same, the "*less*" the strength; the strength then varies "*inversely*" as the length; let $l =$

length in feet, b = breadth in inches, d = depth in inches, and W = breaking weight in cwts., then

$$W = \frac{bd^2}{l}$$

This represents the laws described above when expressed in symbols. In order to apply it to particular cases, it is necessary to multiply by a "*constant*," which is a fixed quantity for similar cases; for wood beams the constant is the central load in cwts. to break beams 1 foot 0 inches × 1 in. × 1 in. The safe load may be taken as one-fifth of the breaking weight for ordinary cases, and one-tenth for moving loads.

The empirical formula may then be stated thus—

$$W = \frac{k \times b \times d^2}{l}$$

The table giving breaking weights of beams 12 inches long, 1 inch broad, 1 inch deep, when loaded in the centre and supported at ends, determined by experiment, and termed the value of k, is given in the chapter on Timber.

To apply the formula, take the case of an English oak beam 12 feet 0 inches × 9 inches × 6 inches to find the safe load.

Constant k for English oak = 4·5.

$$W = \frac{kbd^2}{l}$$

$$= \frac{4·5 \times 6 \times 81}{12} = \frac{4·5 \times 81}{2}$$

$$= 182\tfrac{1}{4} \text{ cwts. central.}$$

$$\text{Safe load} = \frac{182\frac{1}{4}}{5} = 36·45 \text{ cwts. central}$$

$$= 72·9 \text{ cwts. distributed.}$$

It is necessary always to remember that the constants are for beams with central loads; to apply to other cases,

the bending moment or leverage effect of the load must be taken into account in the following manner :—

(*a*) *Distributed Load.*—The bending moment or leverage of the load is one-half, consequently the beam will bear twice as much.

$$W = \frac{2kbd^2}{l}$$

(*b*) *Cantilever Distributed Load.*—The leverage or bending moment of the load is double that of the same beam loaded at centre and ends supported, consequently the strength is only one-half.

$$W = \frac{kbd^2}{2l}$$

(*c*) *Cantilever End Load.*—The leverage of the load is four times as much as in the beam supported at both ends with central load.

$$W = \frac{kbd^2}{4l}$$

(*d*) Beam with concentrated load. Find W as for central load and then multiply the result by the square of half the length and divide the product by the product of the segments.

The following will illustrate a case. Determine the W or breaking weight of a beam of northern pine placed 3 feet and 7 feet from supports :—

$$\begin{aligned} W &= \frac{k \times b \times d^2}{l} \times \frac{5 \times 5}{3 \times 7} \\ &= \frac{4 \times 3 \times 9^2}{10} \times \frac{25}{21} \\ &= 97{\cdot}2 \times \frac{25}{21} \\ &= 115{\cdot}7 \text{ cwts.} \end{aligned}$$

Strongest and Stiffest Section.—The strongest girder out of a given log is that which will carry the most weight before breaking, and obtains the maximum value of the breadth multiplied by the square of the depth (bd^2) ; the ratio of breadth to depth will be nearly as 7 is to 10.

The stiffest girder which can be obtained from the log is that which will resist the greatest amount of "deflection" or "sagging" under a load, and obtains the maximum value of the breadth multiplied by the cube of the depth (bd^3); the ratio of breadth to depth will be nearly as 6 is to 10.

The method of determining graphically the strongest rectangular beam that can be cut out of a circular log is to divide a diameter into three equal parts, and from each point so determined draw a perpendicular one on each side the diameter, and at the points where these cut the circumference, draw straight lines to both ends of the diameter. The rectangle thus formed is the strongest section, as shown in figure 363.

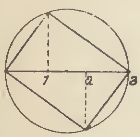


Fig. 363.

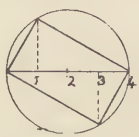


Fig. 364.

The method of finding the stiffest rectangular section is similar to the above, the diameter being divided into four equal parts, the perpendiculars being set up from the two outside points of division, as shown in figure 364.

Application of Rational Formulæ to Rectangular Sections.

The rational formula is applied to rectangular sections as follows:—

Let C = the value of the co-efficient of rupture per square inch of section and is usually taken as 18 times the value of K given in the chapter on Timber.

l, b, and d = length, breadth, and depth in same units usually in inches.

W = breaking weight in same units as C usually cwts.

I = moment of inertia for rectangular sections the value of which is $\frac{bd^3}{12}$

δ = depth $\div$ 2 being the distance of the extreme fibres from the neutral axis $= \frac{d}{2}$

Then $ML = MR$

$$= \frac{CI}{\delta}$$

$$= \frac{C\frac{bd^3}{12}}{\frac{d}{2}}$$

$$= \frac{Cbd^2}{6}$$

The value of C may be given in terms of K as follows :—

K is the value of the experimental breaking weight per square inch, C is the value of the theoretical co-efficient of rupture or breaking stress per square inch, it is for timber neither the tensile nor compressible breaking stress per square inch, but is a theoretical value somewhat between the two. It may be expressed in terms of the empirical value of K as follows :—

Let a rectangular beam centrally loaded be taken, then

EMPIRICAL VALUE.

$$W = \frac{Kbd^2}{l}$$

let l be given in inches as in the rational formula then

$$W = \frac{Kbd^2}{\frac{l}{12}}$$

$$= \frac{12Kbd^2}{l}$$

$$K = \frac{lW}{12bd^2}$$

RATIONAL FORMULA.

$$\frac{Wl}{4} = \frac{Cbd^2}{6}$$

$$C = \frac{6Wl}{4bd^2}$$

that is,

$$K = \tfrac{1}{12} \quad \text{when} \quad C = \tfrac{3}{2} = \tfrac{18}{12}$$

$$\therefore \quad C : K :: 18 : 1$$

$$\text{that is } C = 18K$$

The following will illustrate the application of the above :—

A distributed load of 80 cwts. is to be carried safely over a span of 13 feet 4 inches by a fir-bressummer without lateral support. In this case the minimum breadth would have to be that determined by the formula for stiffness.

If 80 cwts. has to be carried safely, the W or breaking weight must equal 400 cwts.

$$\text{ML} = \text{MR}$$

$$\frac{wl^2}{8} = \frac{c \times b \times d^2}{6}$$

$$\frac{\frac{400}{160} \times 160^2}{8} = \frac{63 \times \cdot 6d \times d^2}{6}$$

$$8000 = 6 \cdot 3d^3$$

$$d = 10 \cdot 7 \text{ nearly.}$$

$$b = \cdot 6d = \cdot 6 \times 10 \cdot 7 = 6 \cdot 42, \text{ say } 11 \text{ in.} \times 6\tfrac{1}{2} \text{ in.}$$

That is, this beam would break with a distributed load of 400 cwts., and would therefore carry safely 80 cwts.

Flitched Girders.—Timber is often employed for girders and beams when required for bridging openings and carrying loads. In order to ensure soundness of the material, the log is cut longitudinally depthways, and the two parts are then placed together with the freshly cut surfaces on the outside; this process is called "halving."

As the butt end of a tree is to the upper end in ratio of strength as 8 to 7, in order to equalize the strength, one piece is turned end for end, and this is called "reversing," as described in the *Elementary Course* in the chapter on Girders.

The strength of such can be ascertained by the equation:—

$$\text{BW} = \frac{k \times b \times d^2}{l}$$

when loaded at the centre, and

$$\text{BW} = \frac{2k \times b \times d^2}{l}$$

when the load is distributed.

BW is the breaking weight estimated in cwts., and b and d represent the breadth and depth in inches, and l the length in feet, k is a constant varying with the material, and is the breaking weight in cwts. of a piece 1 foot long, 1 in. × 1 in. load in the centre; for northern pine this may be taken as 4 cwts., for wrought iron 18 cwts.

To add to the strength, a plate of wrought iron or mild steel termed a flitch is introduced or sandwiched between the halved timbers, and the whole bolted together, as shown in figure 449, *Elementary Course.*

This composite beam is termed a flitched girder or sandwiched beam, and its strength will be the strength of the timber plus the strength of the iron, the equation being when under a distributed load:—

BW = strength of the wood + strength of the iron

$$= \frac{2k \times b \times d^2}{l} + \frac{2k_1 \times b_1 \times d_1^2}{l_1}$$

where k is the constant and b, d, and l the dimensions for the flitch.

EXAMPLE: A beam is to carry safely a distributed load of 7 tons over an opening of 12 feet. Of what section should it be in Memel fir with a wrought-iron flitch?

If the beam is to carry safely 7 tons, the breaking weight will be five times the safe load, then 5 × 7 tons = 35 tons or 700 cwts.

Let x equal the total breadth of the timber, which to obtain the maximum stiffness should be to the depth as 6 is to 10. The thickness of the wrought-iron flitch is usually one-twelfth of the breadth of the timber, and therefore equals

$$\frac{x}{12} = \frac{\cdot 6d}{12} = \cdot 05d.$$

Breaking weight = strength of timber + strength of iron,

$$700 = \frac{2k \times b \times d^2}{l} + \frac{2k \times b \times d^2}{12}$$

$$700 = \frac{2 \times 4 \times \cdot 6d \times d^2}{12} + \frac{2 \times 18 \times \cdot 05d \times d^2}{12}$$

$$700 = \cdot 4d^3 + \cdot 15d^3$$

$$700 = \cdot 55d^3$$

$$d^3 = \frac{14000}{11}$$

$$d = \sqrt[3]{1272 \cdot 7}$$

$$d = 10 \cdot 9 \text{ nearly.}$$

$$b = \cdot 6d \therefore \cdot 6 \times 10 \cdot 9 = 6 \cdot 54 \text{ inches.}$$

Thickness of flitch $= \cdot 05d \times 10 \cdot 9 = \cdot 545 =$ say $\frac{9}{16}$ inch.

Say 11 in. × 6 in. for Memel fir beam and 11 in. × $\frac{9}{16}$ in. wrought-iron flitch.

It is usual and wise to arrange that the depth of the fir beam is $\frac{1}{2}$ inch more than the depth of the iron flitch, to prevent any danger resulting from the fir shrinking, and the load riding on the iron flitch.

Deflection of Beams.—It is often necessary in practice to inquire into the probable amount of deflection of beams, as in many instances beams otherwise sufficiently strong for their purpose bend and tend to make unstable such materials as plaster, added to which the continuous action through any great space of the material of which a beam is formed, tends to overcome the cohesion of the molecules, and thus wears out or reduces the resisting value of the beam.

The formula to determine deflection of any material under any load, as given by Rankine and Wray, is as follows:—

$$\Delta = \frac{n''' \, Wc^3}{EI}$$

when

n''' = factor of relative value.
W = load.
c = length of semi-beam in inches or half the length in beams supported each end.
E = modulus of elasticity.
I = moment of inertia.

All dimensions to be in inches and weight in lbs.

Deflection of fixed beams as given by Humber is one-fourth that of same beams if not fixed at ends.

VALUES OF n'''.

	Uniform Cross Section.	Uniform Strength and Uniform Depth.	Uniform Strength and Uniform Breadth.
Fixed at one end, loaded at other	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$
,, ,, ,, ,, loaded uniformly	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$
Supported at both ends, loaded in the middle	$\frac{1}{6}$	$\frac{1}{4}$	$\frac{1}{3}$
,, ,, ,, ,, uniformly loaded ...	$\frac{5}{48}$	$\frac{1}{8}$	0·1427

If the above values of n''' be divided by 8, then the total length of a beam supported each end will be the value of c.

SPECIAL FORMULÆ TO BE APPLIED FOR EACH PARTICULAR CASE.

Fixed at one end, loaded at the other	$\Delta = \frac{Wl^3}{3EI}$	$\Delta = \frac{Wl^3}{2EI}$	$\Delta = \frac{2Wl^3}{3EI}$
Fixed at one end, loaded uniformly	$\Delta = \frac{Wl^3}{8EI}$	$\Delta = \frac{Wl^3}{4EI}$	$\Delta = \frac{Wl^3}{2EI}$
Supported at both ends, loaded in the middle ...	$\Delta = \frac{Wl^3}{48EI}$	$\Delta = \frac{Wl^3}{32EI}$	$\Delta = \frac{Wl^3}{24EI}$
Supported at both ends, uniformly loaded	$\Delta = \frac{5Wl^3}{384EI}$	$\Delta = \frac{Wl^3}{64EI}$	$\Delta = \frac{1427Wl^3}{80000EI}$

YOUNG'S MODULUS, OR THE MODULUS OF ELASTICITY OR VALUE OF E.

	In lbs. per square inch.
Cast Iron	17,000,000
Wrought Iron	29,000,000
Steel, Mild	30,000,000
Oak	1,000,000
Northern Pine	1,000,000 to 1,400,000

The limit of elasticity for timber, cast iron, wrought iron and steel may be taken as $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{5}$ respectively of the forces required to produce rupture.

The Numerical Value of Inertia.—The moment of inertia for numerous sections may be deduced if the following is understood :—

Let l = length of perpendicular line from any assigned axis
M = mass
n = number of particles per unit of length
then M of line $= l\,n$ when assigned axis is at extremity of line.

The numerical value of the moment of inertia for a line about an assigned axis may be obtained as follows :—

$$\mathrm{I} = \frac{\mathrm{M}}{n}\left(\frac{l}{n}\right)^2 + \frac{\mathrm{M}}{n}\left(\frac{2l}{n}\right)^2 + \frac{\mathrm{M}}{n}\left(\frac{3l}{n}\right)^2 + \&c.$$
$$= \frac{\mathrm{M}l^2}{n^3}(1^2 + 2^2 + 3^2 + \&c.)$$

then by the summation of series

$$\mathrm{I} = \frac{\mathrm{M}l^2}{n^3}\left(\frac{n\,(n+1)\,(2\,n+1)}{6}\right)$$

then by multiplication

$$\mathrm{I} = \frac{\mathrm{M}l^2}{n^3}\left(\frac{n^3}{3} + \frac{n^2}{2} + \frac{n}{6}\right)$$

then placing n^3 within the brackets

$$\mathrm{I} = \mathrm{M}l^2\left(\frac{1}{3} + \frac{1}{2\,n} + \frac{1}{6\,n^2}\right)$$

let $\frac{1}{n}$ be zero

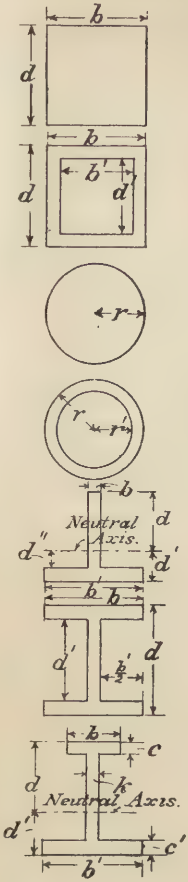
$$\mathrm{I} = \frac{\mathrm{M}l^2}{3}$$

The inertia of half a rectangle about its neutral axis, which is at the centre of the depth of the whole rectangle, and may be obtained by considering it as a number of perpendicular lines about the neutral axis, l here equals $\frac{d}{2}$

$$\therefore\ \ \mathrm{I\ of\ half\ rectangle} = \frac{b \times \frac{d}{2} \times \left(\frac{d}{2}\right)^2}{3}$$
$$= \frac{b\,d^3}{24}$$

$$\therefore\ \ \mathrm{I\ of\ whole\ rectangle} = \frac{2\,b\,d^3}{24} = \frac{b\,d^3}{12}$$ as shown in figure.

NUMERICAL VALUE OF THE MOMENTS OF INERTIA OR I.



$$I = \frac{bd^3}{12}$$

$$I = \frac{bd^3 - b'd'^3}{12}$$

$$I = \cdot 7854 r^4$$

$$I = \cdot 7854 (r^4 - r'^4)$$

$$I = \tfrac{1}{3}\left\{bd^3 + b'd'^3 - (b' - b)d''^3\right\}$$

$$I = \frac{bd^3 - b'd'^3}{12}$$

$$I = \tfrac{1}{3}\left\{bd^3 - (b - k)\ (d - c)^3 + b'd'^3 - (b' - k)\ (d' - c')^3\right\}$$

Fig. 365.

Radius of Gyration.—The radius of gyration of a body about a given axis is that length whose square is the mean of all the squares of the distances of the indefinitely small equal particles of the body from the axis, and is the square root

of the number found by dividing the moment of inertia by the mass, and is expressed by the formula $r = \sqrt{\frac{I}{A}}$

Example of Deflection.—Determine the maximum distributed load that can be put on a fir beam 9 in. × $4\frac{1}{2}$ in. over a 12 feet span, so that its deflection shall not exceed $\frac{1}{4}$ inch.

$$\Delta = \frac{n''' \, W \, C^3}{E \, I}$$

$$\frac{1}{4} = \frac{\frac{5}{48} \times W \times 72^3}{1{,}000{,}000 \times \frac{b \times d^3}{12}}$$

$$\frac{1}{4} = \frac{\frac{5}{48} \times W \times 72^3}{1{,}000{,}000 \times \frac{4\frac{1}{2} \times 9^3}{12}}$$

$$W = 1{,}758 \text{ lbs. nearly.}$$

Beams directly supporting plastering should not deflect more than $\frac{1}{480}$ of their length, otherwise the plastering will tend to crack; in other cases $\frac{1}{360}$ of their length should be the maximum deflection permissible.

RIVETING.

Generally.—Rivets are permanent fastenings used to secure wrought iron and steel plates together. They are not so liable to become loose when subjected to wear as bolts and nuts, as the contraction of the rivets in cooling causes a frictional resistance between the plates equal to 5 tons per square inch of rivet section when the rivet heads are hammered up hot, which is the practice for girders, etc. They are preferable to bolts for constructional members that are not required to be taken apart. It is not usual to make rivets of a diameter larger than $\frac{7}{8}$ inch; if required of greater diameter, bolts are used owing to the difficulty of effectively snapping up the heads.

Rivets should be at least $1\frac{1}{2}$ diameters apart, and their own diameter away from the edge of the plate. The

effective sectional area of a tensional plate is its sectional area, less the space occupied by rivet holes taken through the lines of fracture; this line of fracture is a line cut through the diameter of the first or end row of rivets across the shortest direction from rivet to rivet.

With two cover plates each rivet has two sections to resist shearing stress; and only one-half the number of rivets are necessary than when only one cover-plate is used.

The bearing area of a rivet is its diameter multiplied by the thickness of the plate; and the bearing area of the rivets must be sufficient to withstand the stress.

Chain Riveting.—In chain riveting the rivets are arranged in parallel straight rows, both across and longitudinally at right angles to each other.

In zigzag or alternative riveting the rivets are arranged in straight lines diagonally across the plate, and longitudinally they run in parallel lines, every alternate rivet being opposite.

Zigzag riveting is the more economical method for resisting tensional stress.

The principle in designing riveted joints is that of so proportioning the position and number of rivets that the joints may be equally strong or fail from the rupture of the plate and the shearing of the rivets at the same time.

The "pitch" of rivets is their distance apart from centre to centre. The ordinary pitches for girder work are 3 and 4 inches, the length of the lap beyond the end row of rivets being half the pitch.

Rivet heads are made in various shapes, such as cup or snap, countersunk, pan, and cheese head, as shown in figures 521 to 524, *Elementary Course.*

Specification.—Rivets should bend double when cold, without any signs of fracture: when hot they should stand their heads being hammered down to less than $\frac{1}{8}$ of an

inch in the thickness, without any cracking at the edges; a punch nearly equal to the diameter of the rivet should be driven through the shank without starting the edges.

A good practical rule is to make the diameter of equal rivets $1 \cdot 2 \sqrt{t}$, when t is equal to the thickness of each of the plates.

Cover Plates. — Thickness of cover plates is usually determined as follows:—

$$\text{Single covers} = t + \frac{t}{8}$$

$$\text{The sum of thickness of double covers} = t + \frac{t}{4}$$

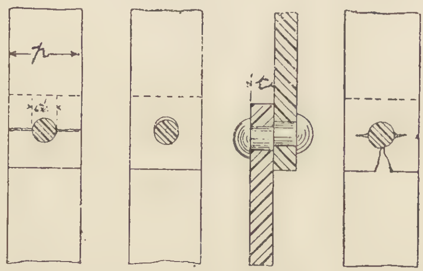


Fig. 366. Fig. 367. Fig. 368. Fig. 369.

Classification of Joints.—Riveted joints for girder work may be classified as follows:—

(*a*) Single riveted lap, (*b*) double riveted lap, (*c*) single riveted fish or butt joint, (*d*) double riveted fish or butt joint, (*e*) single riveted fish or butt joint, with two covers, (*f*) double riveted fish or butt joint with two covers.

Economical Disposition of Wrought Iron and Mild Steel Rivets.—Unwin gives the following as satisfying the greatest economy of material in a riveted joint:—

Let d = diameter of rivets after riveting
p = pitch of rivets
t = thickness of plates

l = semi-overlap or distance from centre of rivet to edge of plate
f_t = tenacity of material of plates
f_c = resistance to crushing of plates or rivets
f_s = shearing resistance of rivets
T = resistance of a strip of a joint of width p.

A riveted joint may be considered either as formed of a number of strips, or its weakest part to resist tensile, compressile, or bearing area stresses, and the resistance of the rivets to shear.

1. The weakest part of the plate to tear across is along the line of minimum section, as shown in figure 366. The tensile area of the plate is therefore $(p\text{-}d)\,t$—

$$T = (p\text{-}d)\,t\,f$$

2. The plate and rivet may be crushed, as shown in figure 367. The area of the plate or rivet supporting the pressure is $d\,t$, and this is called the bearing area.

$$T = d\,t\,f_c$$

3. The rivet may shear across, as shown in figure 368.

$$T = \frac{\pi}{4}\,d^2\,f_s$$

4. The plate may break across in front of the rivet, as shown in figure 369, the action being similar to the transverse fracture of a bar fixed at ends loaded in the centre—

$$T = \tfrac{1}{3}\,\frac{(2\,l\text{-}d)^2\,t\,f_t}{d}$$

but if the semi-overlap be at least $\frac{3}{2}d$—it is generally in practice considerably more—this formula becomes unnecessary to use.

Calculations.—The following may be useful to illustrate the application of the formulæ. They are the calculations of the riveted joints for the wrought iron girder, the drawing of which is shown in figures 355 to 359. If the girder and the rivets are of mild steel, exactly similar calculations for the determination of the number of rivets and the

disposition of the joists are required, increased values being given for f_c, f_t and f_s.

Rivets for web covers are $\frac{5}{8}$ inch in diameter. Let f_t and f_c be taken as 5 tons safe stress, f_s as 4 tons safe stress, and S equals stress $= n$ T.

Web Covers.—The stress measured from shearing diagram at joint is 11 tons. Calculate number of $\frac{5}{8}$ inch rivets required.

Let $n =$ number of rivets required then for bearing area—

$$S = n\,d\,t\,f_c$$
$$n = \frac{S}{d \times t \times f_c}$$
$$= \frac{11}{\cdot 625 \times \cdot 375 \times 5}$$
$$= 10 \text{ rivets nearly.}$$

The rivets may be cut or sheared, and as they must come into double shear by having two cover plates, then by formula 3,—

$$S = 2\,n\,\frac{\pi}{4}\,d^2\,f_s$$
$$= \frac{11}{\cdot 7854 \times \cdot 39 \times 4 \times 2}$$
$$= 5 \text{ rivets nearly.}$$

Bearing area, therefore, determines the number of rivets.

TO DETERMINE THICKNESS OF WEB.

Thickness of Web.—Let h = distance between angle irons, which is 28 inches, the net sectional length will equal, as there are seven $\frac{5}{8}$ inch rivets, $23\frac{5}{8}$ inches.

$$S = n\,(p\text{-}d)\,t \times \text{factor for shearing stress}$$
$$t = \frac{11}{23\frac{5}{8} \times 4}$$
$$t = \cdot 12 \text{ inch thickness}$$

But webs should never be less than $\frac{1}{4}$ inch in thickness, and to allow for rusting keep the web its required maximum thickness at the ends, viz., $\frac{3}{8}$ inch thickness.

Cover Plates.—The sum of thickness of cover plates should equal—

$$2 \text{ cover plates} = t + \frac{t}{4}$$
$$= {}^{\cdot}375 + \frac{{}^{\cdot}375}{4}$$
$$= {}^{\cdot}468, \text{ say } \tfrac{1}{2} \text{ inch}$$

and $\frac{1}{2}$ inch divided by 2 = $\frac{1}{4}$ inch thickness of each cover plate.

Tensional Flange.—Cover plate to form joint in $\frac{3}{8}$ inch plate. Determine working stress as follows:—Size of plate $14 \times \frac{3}{8}$ and for net sectional area deduct two $\frac{3}{4}$ rivet holes $= [14 - (2 \times {}^{\cdot}75)]\ {}^{\cdot}375 = 4{\cdot}7$ inches area and multiplied by 5 (factor of safety for tension) = $23{\cdot}5$ tons working stress of plate.

To determine number of rivets to resist bearing stress by formula 2.

$$S = d \times t \times 5 \times n$$
$$\text{that is } n = \frac{23{\cdot}5}{{}^{\cdot}75 \times {}^{\cdot}375 \times 5}$$
$$\therefore n = \text{nearly 17 rivets.}$$

To determine number of rivets required to resist shearing stress by formula 3, this case being a butt joint with a single cover.

$$S = {}^{\cdot}7854 \times d^2 \times 4 \times n$$
$$\text{that is } n = \frac{23{\cdot}5}{{}^{\cdot}7854 \times {}^{\cdot}75^2 \times 4}$$
$$n = 14 \text{ nearly.}$$

Minimum number of rivets determined by resistance to bearing stress 17. But the clenching power of the rivets is worth something, although usually neglected, so we can with safety determine the number to be 16 on each side of joint. The rivets may be arranged in zigzag manner, making length of cover plate over all 3 feet, as shown in figures 355 to 359.

Thickness of single cover plate,

$$= t + \frac{t}{8} = \tfrac{3}{8} + \tfrac{3}{64} = \tfrac{27}{64}, \text{ say } \tfrac{7}{16} \text{ inch thickness.}$$

Compressional Flange.—Cover plate to form joint in $\frac{1}{2}$ inch plate.

Determine working stress as follows: Dimensions of plate 14 in. × $\frac{1}{2}$ in. = 7 in. area, and 7 multiplied by 4, factor of safety for compression = 28 tons working stress, then to determine number of rivets to resist bearing stress by formula 2.

$$S = d \times t \times n \times 5 \therefore n = \frac{S}{d \times t \times 5}$$

$$n = \frac{28}{\cdot 75 \times \cdot 5 \times 5} \therefore n = \frac{28}{1\cdot 875}$$

$$n = \text{nearly 15 rivets.}$$

To determine number of rivets to resist shearing stress by formula 3.

$$S = \cdot 7854 \times d^2 \times 4 \times n \therefore n = \frac{S}{\cdot 7854 \times d^2 \times 4}$$

$$\therefore n = \frac{28}{1\cdot 76} \qquad \therefore n = \text{nearly 16.}$$

Minimum number of rivets determined by resistance to shearing stress 16.

Length of cover plate same as for tension flange.

Thickness of single cover plate:

$$= t + \frac{t}{8} = \frac{1}{2} + \frac{1}{16} = \frac{9}{16}$$

Jointing Plates for Angle Irons.—Jointing plate to form joint in 4 in. × 4 in. × $\frac{1}{2}$ in. angle irons.

Determine working stress on 4 in. × 4 in. × $\frac{1}{2}$ in. angle irons.

Gross area 3·75, net area = 3·75 − (·75 × ·5) loss by one $\frac{3}{4}$ rivet hole = 3·375 and 3·375 multiplied by 5 factor of safety in tension = 16·875 working stress on angle irons.

To determine number of rivets to resist bearing stress by formula 2.

$$S = d \times t \times n \times 5 \therefore n = \frac{S}{d \times t \times 5}$$

$$\text{that is } n = \frac{16\cdot 875}{\cdot 75 \times \cdot 5 \times 5} \therefore n = 9.$$

To determine number of rivets to resist shearing stress by formula 3.

$$S = \cdot 7854 \times d^2 \times n \times 4 \therefore n = \frac{16 \cdot 875}{\cdot 7854 \times \cdot 5625 \times 4}$$

$$\text{that is } n = \frac{16 \cdot 875}{1 \cdot 76} \therefore n = \text{nearly } 10.$$

Ten rivets required on each side of joint and the horizontal distance between centre lines of rivets being 2 inches, length of jointing plate = (10 × 2) + 2 inches for overlap = 1 foot 10 inches, and 1 foot 10 inches multiplied by 2 = 3 feet 8 inches total length of the jointing plate in the tensional flange.

In the compressional flange the pitch is 3 inches, equals $1\frac{1}{2}$ inches between centre lines of rivets, = 11 inches × $1\frac{1}{2}$ inches = $16\frac{1}{2}$ inches on each side of joint, and multiplied by 2, equals 2 feet 9 inches total length of the jointing plate.

BRITISH STANDARD SECTIONS.

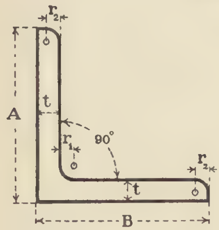
The following tables contain a list of the standardised steel sections, comprising all the angle, zed, channel, beam and tee sections, approved by the Engineering Standards Committee, July, 1904, by whose permission they are here reprinted.

The calculated values of the centre of gravity, moments of inertia, radii of gyration and moments of resistance for these sections are given in the official publication (No. 6) of the Engineering Standards Committee. The methods of calculating these values, which the student may usefully make and tabulate, are described in the chapters on Graphic Statics and Girders, and also an example is given, determining the value of I, on page 219.

For the design of all steel construction it will undoubtedly be found that these tables will prove most useful and practically indispensable.

BRITISH STANDARD SECTIONS

EQUAL ANGLES



a = Sectional Area.

W = 3·4 **a** Weight in lbs. per foot

1	2	3	4	5	6	7
Reference No and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	A × B	t	r_1	r_2	w	a
	inches	inches	inches		lbs.	inches²
BSEA 1 **Abacist**	1 × 1	·125 — ·250	·175	·125	·80 — 1·49	·234 — ·437
BSEA 2 **Aback**	1¼ × 1¼	·125 — ·250	·200	·150	1·02 — 1·92	·299 — ·564
BSEA 3 **Abaddon**	1½ × 1½	·125 — ·250	·200	·150	1·23 — 2·34	·361 — ·689
BSEA 4 **Abaft**	1¾ × 1¾	·175 — ·300	·225	·150	1·98 — 3·27	·583 — ·961
BSEA 5 **Abandoning**	2 × 2	·175 — ·300	·250	·175	2·28 — 3·77	·670 — 1·110
BSEA 6 **Abasement**	2¼ × 2¼	·175 — ·300	·250	·175	2·57 — 4·28	·757 — 1·260
BSEA 7 **Abashed**	2½ × 2½	·250 ·375 ·500	·275	·200	4·04 5·89 7·65	1·187 1·733 2·249

BRITISH STANDARD SECTIONS

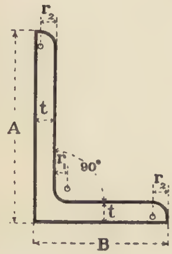
EQUAL ANGLES

(continued)

1	2	3	4	5	6	7
Reference No. and Code Word.	Size.	Standard Thickness	Radii		Weight per foot.	Sectional Area
	A × B	t	r_1	r_2	w	a
	inches	inches	inches		lbs.	inches²
BSEA 8 Abashing	2¾ × 2¾	·250 ·375 ·500	·275	·200	4·46 6·53 8·50	1·312 1·921 2·499
BSEA 9 Abatable	3 × 3	·250 ·375 ·500	·300	·200	4·90 7·18 9·36	1·440 2·111 2·752
BSEA 10 Abater	3½ × 3½	·300 ·425 ·500	·325	·225	6·84 9·50 11·05	2.011 2·795 3·251
BSEA 11 Abatjour	4 × 4	·300 ·425 ·500	·350	·250	7·85 10·94 12·75	2·310 3·219 3·749
BSEA 12 Abattis	4½ × 4½	·375 — ·500	·400	·275	11·00 — 14·46	3·236 — 4·252
BSEA 13 Abbacy	5 × 5	·375 — ·500	·425	·300	12·27 — 16·15	3·610 — 4·750
BSEA 14 Abbatial	6 × 6	·450 — ·625	·475	·325	17·68 — 24·18	5·201 — 7·112
BSEA 15 Abbey	7 × 7	·500 — ·675	·550	·375	22·97 — 30·60	6·755 — 8·999
BSEA 16 Abbeyland	8 × 8	·550 — ·750	·600	·425	28·89 — 38·89	8·497 — 11·437

BRITISH STANDARD SECTIONS

UNEQUAL ANGLES



a = Sectional Area.

$W = 3{\cdot}4a$ Weight in lbs. per foot.

1	2	3	4	5	6	7
Reference No. and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	A × B	t	r_1	r_2	W	a
	inches	inches	inches		lbs.	inches^2
BSUA 1 Abbot	1¼ × 1	·125 — ·250	·175	·125	·90 — 1·70	·265 — ·500
BSUA 2 Abbreviate	1½ × 1¼	·125 — ·250	·200	·150	1·11 — 2·12	·327 — ·624
BSUA 3 Abderian	1¾ × 1½	·175 — ·300	·225	·150	1·83 — 3·01	·539 — ·886
BSUA 4 Abdicable	2 × 1½	·175 — ·300	·225	·150	1·98 — 3·27	·583 — ·961
BSUA 5 Abdicated	2½ × 2	·175 — ·300	·250	·175	2·57 — 4·28	·757 — 1·260
BSUA 6 Abdicating	3 × 2	·250 ·375 ·500	·275	·200	4·04 5·89 7·65	1·187 1·733 2·249
BSUA 7 Abdicatrix	3 × 2½	·250 ·375 ·500	·275	·200	4·46 6·53 8·50	1·312 1·921 2·499
BSUA 8 Abditory	3½ × 2½	·250 ·375 ·500	·300	·200	4·90 7·18 9·36	1·440 2·112 2·752

BRITISH STANDARD SECTIONS

UNEQUAL ANGLES

(continued)

1	2	3	4	5	6	7
Reference No and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	A × B	t	r_1	r_2	w	a
	inches	inches	inches		lbs	inches^2
BSUA 9 Abdominous	3½ × 3	·250 ·375 ·500	·325	·225	5·31 7·81 10·20	1·563 2·298 3·001
BSUA 10 Abducting	4 × 2½	·250 ·375 ·500	·325	·225	5·31 7·81 10·20	1·563 2·298 3·001
BSUA 11 Abecedary	4 × 3	·300 ·425 ·500	·325	·225	6·84 9·50 11·05	2·011 2·795 3·251
BSUA 12 Abelite	4 × 3½	·300 ·425 ·500	·350	·250	7·34 10·22 11·90	2·159 3·006 3·499
BSUA 13 Abelmosk	4½ × 3	·300 ·425 ·500	·350	·250	7·34 10·22 11·90	2·159 3·006 3·499
BSUA 14 Abelonian	4½ × 3½	·300 ·425 ·500	·350	·250	7·85 10·94 12·75	2·309 3·219 3·749
BSUA 15 Abeltree	5 × 3	·300 ·425 ·500	·350	·250	7·85 10·94 12·75	2·309 3·219 3·749
BSUA 16 Aberrancy	5 × 3½	·375 — ·500	·375	·250	10·37 — 13·61	3·050 — 4·003
BSUA 17 Aberration	5 × 4	·375 — ·500	·400	·275	11·00 — 14·46	3·236 — 4·252
BSUA 18 Abetment	5½ × 3	·375 — ·500	·375	·250	10·37 — 13·61	3·050 — 4·003
BSUA 19 Abetted	5½ × 3½	·375 — ·500	·400	·275	11·00 — 14·46	3·236 — 4·252

BRITISH STANDARD SECTIONS

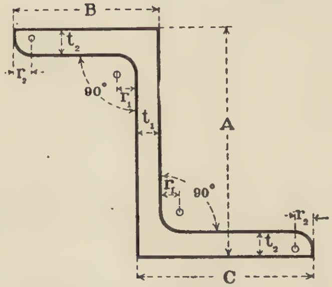
UNEQUAL ANGLES

(continued)

1	2	3	4	5	6	7
Reference No. and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	A × B	t	r_1	r_2	W	[illegible]
	inches	inches	inches		lbs.	inches²
BSUA 20 Abetting	6 × 3½	·375 — ·500	·400	·275	11·64 — 15·31	3·424 — 4·502
BSUA 21 Abettors	6 × 4	·375 — ·500	·425	·300	12·27 — 16·15	3·610 — 4·750
BSUA 22 Abeyance	6½ × 3½	·375 — ·500	·425	·300	12·27 — 16·15	3·610 — 4·750
BSUA 23 Abhorrency	6½ × 4	·525	·425	·300	17·81	5·237
BSUA 24 Abhorrible	6½ × 4½	·550	·450	·325	19·54	5·746
BSUA 25 Abhorring	7 × 3½	·525	·425	·300	17·81	5·237
BSUA 26 Abiders	7 × 4	·550	·450	·325	19·54	5·746
BSUA 27 Abidingly	8 × 3½	·575	·475	·325	21·37	6·285
BSUA 28 Abietic	8 × 4	·625	·475	·325	24·18	7·112
BSUA 29 Abigail	9 × 4	·650	·500	·350	27·30	8·029
BSUA 30 Abilities	10 × 4	·675	·550	·375	30·60	8·999

BRITISH STANDARD SECTIONS

Z BARS



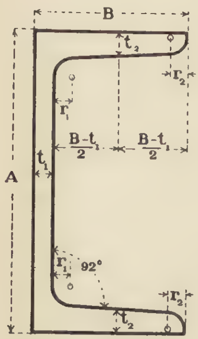
a = Sectional Area.

W = 3·4 a Weight in lbs. per foot.

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B × C	t_1	t_2	r_1	r_2	W	a
	inches	inches		inches		lbs.	inches²
BSZ 1 Abominable	3 × 2½ × 3	·300	·400	·325	·225	9·81	2·884
BSZ 2 Abominated	4 × 2½ × 3	·325	·425	·350	·225	11·63	3·392
BSZ 3 Abominator	5 × 3 × 3	·350	·450	·375	·250	14·17	4·169
BSZ 4 Aborally	6 × 3½ × 3½	·375	·475	·425	·300	17·88	5·258
BSZ 5 Aboriginal	7 × 3½ × 3½	·400	·500	·450	·300	20·22	5·948
BSZ 6 Aborigines	8 × 3½ × 3½	·425	·525	·450	·325	22·68	6·670
BSZ 7 Abortional	9 × 3½ × 3½	·450	·550	·475	·350	25·33	7·449
BSZ 8 Abortively	10 × 3½ × 3½	·475	·575	·500	·350	28·16	8·283

BRITISH STANDARD SECTIONS

CHANNELS



a = Sectional Area.

w = 3·4 **a** Weight in lbs. per foot.

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs	inches²
BSC 1 Abound	3 × 1½	·250	·312	·312	·220	5·27	1·549
BSC 2 Aboundeth	3½ × 2	·250	·312	·312	·220	6·75	1·986
BSC 3 Aboveboard	4 × 2	·250	·375	·375	·260	7·96	2·341
BSC 4 Abovecited	5 × 2½	·312	·375	·375	·260	10·98	3·230
BSC 5 Abovesaid	6 × 2½	·312	·375	·375	·260	12·04	3·542
BSC 6 Abrade	6 × 3	·312	·437	·437	·300	14·49	4·261
BSC 7 Abrading	6 × 3	·375	·475	·475	·325	16·29	4·791

BRITISH STANDARD SECTIONS

CHANNELS

(continued)

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs.	inches²
BSC 8 Abrasion	6 × 3½	·375	·475	·475	·325	17·90	5·266
BSC 9 Abrazite	7 × 3	·375	·475	·475	·325	17·56	5·166
BSC 10 Abreast	7 × 3½	·400	·500	·500	·350	20·23	5·950
BSC 11 Abrenounce	8 × 2½	·312	·437	·437	·300	15·12	4·448
BSC 12 Abridged	8 × 3	·375	·500	·500	·350	19·30	5·675
BSC 13 Abridging	8 × 3½	·425	·525	·525	·375	22·72	6·682
BSC 14 Abridgment	8 × 4	·450	·550	·550	·375	25·73	7·569
BSC 15 Abroach	9 × 3	·375	·437	·437	·350	19·37	5·696
BSC 16 Abrogable	9 × 3½	·375	·500	·500	·350	22·27	6·550
BSC 17 Abrogates	9 × 3½	·450	·550	·550	·375	25·39	7·469
BSC 18 Abrogating	9 × 4	·475	·575	·575	·400	28·55	8·396
BSC 19 Abrogation	10 × 3½	·375	·500	·500	·350	23·55	6·925
BSC 20 Abrook	10 × 3½	·475	·575	·575	·400	28·21	8·296

BRITISH STANDARD SECTIONS

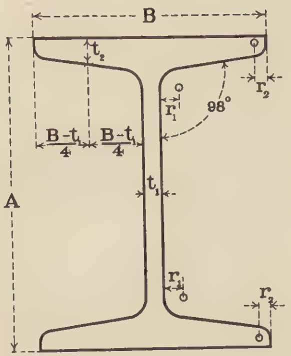
CHANNELS

(continued)

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs.	inches^2
BSC 21 Abrotanoid	10 × 4	·475	·575	·575	·400	30·16	8·871
BSC 22 Abrothrix	11 × 3½	·475	·575	·575	·400	29·82	8·771
BSC 23 Abrupt	11 × 4	·500	·600	·600	·425	33·22	9·771
BSC 24 Abruption	12 × 3½	·375	·500	·500	·350	26·10	7·675
BSC 25 Abruptly	12 × 3½	·500	·600	·600	·425	32·88	9·671
BSC 26 Abruptness	12 × 4	·525	·625	·625	·425	36·47	10·727
BSC 27 Abscess	15 × 4	·525	·630	·630	·440	41·94	12·334

BRITISH STANDARD SECTIONS

BEAMS



a = Sectional Area.

w = 3·4 **a** Weight in lbs. per foot.

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs.	inches²
BSB 1 Abscession	3 × 1½	160	·248	·260	·130	4·00	1·176
BSB 2 Abscind	3 × 3	·200	·332	·300	·150	8·50	2·501
BSB 3 Absconding	4 × 1¾	·170	·240	·270	·135	5·00	1·472
BSB 4 Absented	4 × 3	·220	·336	320	160	9·50	2·795
BSB 5 Absentees	4¾ × 1¾	·180	·325	280	·140	6·50	1·912
BSB 6 Absenting	5 × 3	·220	376	·320	·160	11·01	3·238
BSB 7 Absently	5 × 4½	·290	·448	·390	195	17·99	5·290

BRITISH STANDARD SECTIONS

BEAMS

(continued)

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs.	inches²
BSB 8 Absentness	6 × 3	·260	·348	·360	·180	11·99	3·527
BSB 9 Absinthe	6 × 4½	·370	·431	·470	·235	20·00	5·882
BSB 10 Absinthine	6 × 5	·410	·520	·510	·255	25·00	7·354
BSB 11 Absolute	7 × 4	·250	·387	·350	·175	16·01	4·709
BSB 12 Absolution	8 × 4	·280	·402	·380	·190	18·01	5·297
BSB 13 Absolutory	8 × 5	·350	·575	·450	·225	28·02	8·241
BSB 14 Absolvable	8 × 6	·440	·597	·540	·270	35·00	10·293
BSB 15 Absolved	9 × 4	·300	·460	·400	·200	21·00	6·178
BSB 16 Absolving	9 × 7	·550	924	·650	·325	58·02	17·064
BSB 17 Absonous	10 × 5	·360	·552	·460	·230	29·99	8·820
BSB 18 Absorb	10 × 6	·400	·736	·500	·250	42·02	12·358
BSB 19 Absorbable	10 × 8	·600	·970	·700	·350	69·98	20·582
BSB 20 Absorbing	12 × 5	·350	·550	·450	·225	31·99	9·408

BRITISH STANDARD SECTIONS

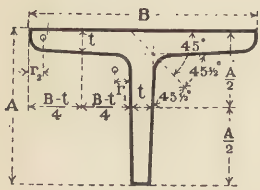
BEAMS

(continued)

1	2	3	4	5	6	7	8
Reference No. and Code Word	Size	Standard Thickness		Radii		Weight per foot	Sectional Area
	A × B	t_1	t_2	r_1	r_2	w	a
	inches	inches		inches		lbs,	inches^2
BSB 21 Absorption	12 × 6	·400	·717	·500	·250	44·02	12·946
BSB 22 Abstain	12 × 6	·500	·883	·600	·300	53·99	15·879
BSB 23 Abstainers	14 × 6	·400	·698	·500	250	46·01	13 533
BSB 24 Abstaining	14 × 6	500	·873	600	300	57·01	16·769
BSB 25 Abstemious	15 × 5	·420	·647	520	·260	41·99	12 351
BSB 26 Abstergent	15 × 6	·500	·880	·600	·300	58·98	17 346
BSB 27 Absterse	16 × 6	550	·847	·650	325	61·97	18·227
BSB 28 Abstersive	18 × 7	·550	·928	650	325	75·02	22·066
BSB 29 Abstinence	20 × 7½	·600	1·010	·700	350	88·96	26 164
BSB 30 Abstorted	24 × 7½	·600	1·070	700	350	99·93	29·392

BRITISH STANDARD SECTIONS

T BARS



a = Sectional Area.

W = 3·4 a Weight in lbs. per foot.

1	2	3	4	5	6	7
Reference No. and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	B × A	t	r_1	r_2	W	a
	inches	inches	inches		lbs.	inches²
BST 1 Abstractly	1 × 1	·125 ·187 —	·175	125	·82 1·17 —	·240 ·344 —
BST 2 Abstruded	1¼ × 1¼	·125 ·187 —	·200	·150	1·03 1·49 —	·303 ·438 —
BST 3 Abstrusely	1½ × 1½	·187 ·250 —	·200	·150	1·81 2·35 —	·531 ·692 —
BST 4 Abstrusion	1¾ × 1¾	·187 ·250 —	·225	·150	2·14 2·79 —	·629 ·820 —
BST 5 Absuming	1½ × 2	·250 ·312 —	·225	·150	2·79 3·40 —	·820 1·001 —
BST 6 Absurd	2 × 2	·250 ·312 ·375	·250	·175	3·22 3·94 4·64	·947 1·159 1·366
BST 7 Absurdest	2¼ × 2¼	·250 ·312 ·375	·250	·175	3·64 4·47 5·28	1·071 1·314 1·553
BST 8 Absurdity	2½ × 2½	·250 ·312 ·375	·275	·200	4·07 5·00 5·92	1·197 1·471 1·741
BST 9 Absurdness	3 × 2	·312 ·375 —	·275	·200	5·01 5·93 —	1·472 1·743 —

BRITISH STANDARD SECTIONS

T BARS

(continued)

1	2	3	4	5	6	7
Reference No. and Code Word	Size	Standard Thickness	Radii		Weight per foot	Sectional Area
	B × A	t	r_1	r_2	w	a
	inches	inches	inches		lbs.	inches²
BST 10 Abterminal	3 × 2½	·312 ·375 —	·275	·200	5·53 6·56 —	1·627 1·929 —
BST 11 Abundance	3 × 3	·312 ·375 ·437	·300	·200	6·08 7·21 8·30	1·788 2·121 2·441
BST 12 Abundant	3 × 4	·375 ·500 —	·325	·225	8·48 11·07 —	2·494 3·256 —
BST 13 Abusable	3½ × 3½	·375 ·437 ·500	·325	·225	8·49 9·78 11·08	2·496 2·878 3·258
BST 14 Abuseful	4 × 3	·375 ·500 —	·325	·225	8·49 11·08 —	2·498 3·260 —
BST 15 Abuseth	4 × 4	·375 ·500 —	·350	·250	9·77 12·78 —	2·872 3·758 —
BST 16 Abusing	4 × 5	·375 ·500 —	·400	·275	11·06 14·50 —	3·253 4·264 —
BST 17 Abusively	5 × 3	·375 ·500 —	·350	·250	9·78 12·79 —	2·875 3·762 —
BST 18 Abuttal	5 × 3½	·500 — —	·375	·250	13·66 — —	4·018 — —
BST 19 Abvolated	5 × 4	·500 — —	·400	·275	14·51 — —	4·268 — —
BST 20 Abysmal	6 × 3	·375 ·500 —	·400	·275	11·08 14·53 —	3·260 4·272 —
BST 21 Abyss	6 × 4	·500 — —	·425	·300	16·22 — —	4·771 — —
BST 22 Acacias	7 × 3½	·500 — —	·425	·300	17·08 — —	5·023 — —

CHAPTER X.

FIRE-RESISTING CONSTRUCTION.

Definition.—Buildings and all parts of buildings designed and arranged to retard the action of fire are termed fire-resisting constructions. Reinforced concrete constructions are given in a separate chapter.

Generally.—Fire-resisting constructions have been the subject of much study during recent years, and considerable advances in this direction have been made in all modern buildings of any importance. The experience obtained from all the great fires of late years, however, leaves no doubt that the construction of a furnace would be necessary to withstand the intense heat of a general conflagration. The whole effort of the designer must, therefore, be to select fire-resisting materials from those at his disposal, and to arrange them to comply with the modern requirements. Up to the present time no building has been erected perfectly fire-proof, though much has been done to render them fire-resisting.

Fire-resisting floors, among their other advantages, are eminently sanitary, and are, therefore, suitable for public buildings, notably hospitals, and are noiseless if covered with a wood-block floor.

Materials.—The necessary characteristics of a typical fire-resisting material are as follows:—1st, It should not consume or become disintegrated under great heat; 2nd, its expansion, when heated, should not be sufficient to

damage the structure of which it forms a part; 3rd, its contraction, when heated to a high temperature and then suddenly cooled with water, should not be sufficiently rapid as to cause it to fly to pieces. Although none of the materials in use possess the whole of the above qualities, many of them resist the action of fire to an extent which renders them valuable for fire-resisting work, and it only remains to adapt them to the requirements of the structure. The materials chiefly used, and their fitness for the four principal parts of any structure, viz., walls, floors, staircases, and roofs, will be described.

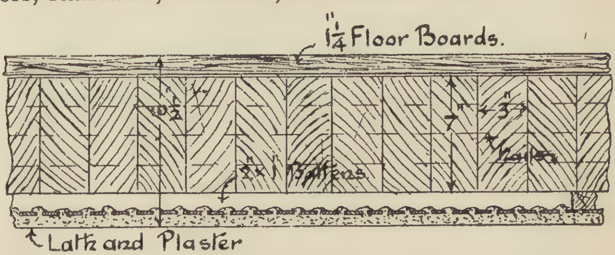


Fig. 370.

Timber.—Buildings constructed of timber, solid for a thickness of at least 7 inches, and arranged to prevent the circulation of air about the pieces, will withstand the effects of fire for a considerable time. Timber arranged to comply with the above conditions is expensive compared with many other systems equally fire-resisting. The Model Bye-Laws prohibit the construction of walls with timber in urban districts. Solid timber floors are effective, but expensive. Wood is being rapidly displaced by steel as a material for constructing roof trusses, owing to the difficulties and expense incurred in adapting timber for large spans; and for the external covering of roofs, it would also be expensive and very heavy, when compared with concrete of equal fire-resisting capacity. For either of these materials it would be necessary to have a weather-proof covering.

Messrs. Evans and Swain have patented a system of adapting timber for the construction of stairs and floors. For floors it consists, as shown in figure 370, of a number of planks laid side by side and spiked together. The ends rest on off-sets from the wall; no wall plates are used. The depth of the timbers varies from $4\frac{1}{2}$ inches in 8 feet to 11 inches in 30 feet spans. To support a plastered ceiling, the soffit is brandered or counter-lathed to obtain the key for the plaster. An alternative method is to cut an angular

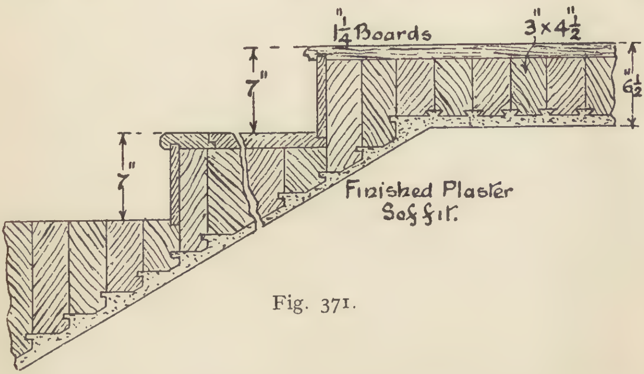


Fig. 371.

rebate in the bottom edges of the timbers, which form dovetailed grooves when put together, thus providing the necessary key.

Stairs are constructed in a similar manner to the floors. If the staircase has a well, and one end of each of the steps is free, the other end is built in the wall. There is a slight difference in the method of forming the key for the plaster —horizontal, rectangular grooves being made, as shown in figure 371.

Solid timber stairs, in which each step is formed of a solid block of oak or other hard wood built into the wall similar to stone steps, have been largely used in old houses —not expressly for fire-resisting purposes, although they

answer well for that—and if the soffit be moulded are very effective, and are even now at times reproduced.

Stone.—Stone is a bad material to resist the action of fire, for when heated and suddenly cooled with water it is liable to fly to pieces, and it is useful only because it is non-combustible. Granite, when subjected to a great heat, crumbles to a fine sand, or cracks and falls to pieces with a series of small explosions. Limestones are calcined and turned to quick lime, the particles of which lose all cohesion when exposed to air and water. Sandstones resist fire better than the previous two, but after a short exposure they become disintegrated.

Bricks.—Bricks form one of the best materials for the construction of walls, which, if well-flushed with good mortar, and of an uninterrupted thickness of at least 9 inches, are practically fireproof; but alone for floors, roofs, and stairs they cannot be economically adopted, as it would be necessary to construct arches, which exert great thrust on the walls, rendering iron ties or thick walls necessary; this is expensive and is a barrier to their use.

Firebricks, from their refractory character, are best; but their comparatively great cost excludes their use for all ordinary works.

"The Builder" of March 12th, 1898, gives the following report of a committee of the Kent and Essex Brickmakers' Association, who have been making an examination of the effects of the fire on the various materials in the houses destroyed in the Cripplegate fire:—

1. Ordinary stock building bricks, quite uninjured.

2. Perforated bricks, broken to pieces, and where used for outside facing the front face was gone, and the perforations exposed.

3. Blue bricks, faces gone.

4. Red bricks, faces gone and destroyed.

5. Stone, cracked and destroyed.

6. Iron girders, mostly twisted up and curled up.

7. Wooden beams, charred, but practically otherwise uninjured.

8. Match-boarding used for panelling the walls, burnt to tinder.

They add that they think the conclusion to be drawn from the action of the fire upon the brickwork is that the stock bricks, although not even of the best quality, were quite unaffected, and they attribute this to the fact that stocks, from the large amount of silica in the brick-earth from which they are made, and from the mode of manufacture, are often of the nature of a fire-brick. Bricks made purely of clay, and especially when made by machinery, were not able to resist the action of the fire.

Terra-cotta.—Terra-cotta is a similar material to brick, its refractory qualities being superior to ordinary bricks, and it is useful for all purposes where brick is used; its expense, however, prevents its use for any but ornamental work. It is chiefly employed in fire-resisting constructions to protect iron girders, columns, and stanchions.

Concrete.—Concrete is used in nearly every form of fire-resisting floor construction, the ease with which it may be adapted to every position and form rendering it peculiarly suitable for this class of work. The manufacture of concrete and the requisite characteristics for every part of a building have been fully described in the article on Concrete.

Cast Iron.—Cast iron when heated and suddenly cooled by water usually flies into fragments; it is, therefore, a bad material for fire-resisting work. Where employed, it should have at least 9 inches of brickwork built about it, or be encased with terra-cotta blocks, a method often employed for columns.

Wrought Iron and Steel.—These two materials when heated have a tendency to twist, due to the softening of the material and the consequent reduction of the resistance to tension and compression, which is increased if the girders or members are fixed; it is important that all such iron-work should be allowed room for expansion, otherwise the walls will be subjected to an overturning thrust; and, also, it should be thoroughly encased with some incombustible material, such as concrete, brick, or terra-cotta. In some conflagrations heated girders have been known to expand $1\frac{5}{8}$ inches in every 10 feet of length.

Timber and Concrete.—This is a system that is useful

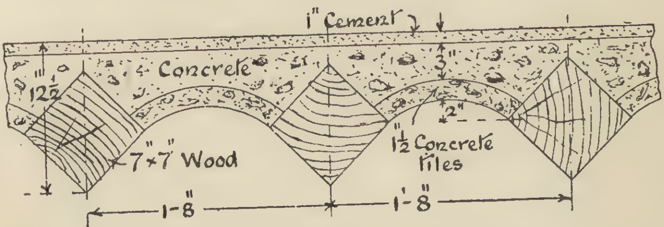


Fig. 372.

where ironwork is scarce or difficult to obtain. Figure 372 shows one arrangement; wooden joists square in section, and of dimensions to suit the span, with one diagonal of the section vertical, to form a skewback upon which segment tiles are bedded, as shown in figure 372, and placed from 1 foot 6 inches to 2 feet apart from centre to centre, the sides of the tiles abutting on the upper inclined surfaces of the timbers. A bed of concrete 6 inches in thickness above the tile is spread over the whole surface. The upper surface may then be floated in cement or a wood floor may be laid.

Timber and Slag Wool Slabs.—Timber floors and half-timber houses are rendered much more fire-resisting if the

intervening spaces are lined or filled in with slag wool slabs.

Brick, Iron, and Concrete.—Fire-resisting floors are constructed consisting of a number of brick arches springing from rolled iron joists, placed about 6 feet apart. In ordinary practice the springers are simply cut to fit the flange of the girder, but in many cases the springers are specially made to cover the bottom flange of the girder, which is a great advantage. To reduce the weight, the bricks are often made less in depth as they get nearer the crown;

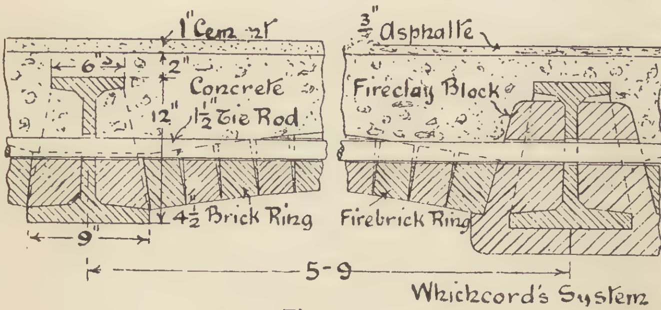


Fig. 373.

hollow bricks have often been employed for the same purpose. To counteract the thrust of the arches, iron rods are employed; these pass through the girders and connect the two extremities of the floor together. The necessity for these is often avoided should cross walls occur at right angles to the two walls receiving the thrust, or by buttressing the two walls, or making them thick enough to counteract the thrust by their weight. The surface of the arch and the top of the girder are covered with concrete, as shown in figure 373.

Concrete Arches.—Floors are constructed similar to those last, but omitting the brick arches, the concrete being

placed on wood centres direct, and enveloping the upper part of the girders. The concrete, when set, forms a slab, and not an arch, and consequently does not transmit any considerable lateral thrust upon the walls, and this does away with the necessity of any tie-bolts, or walls thicker than required to carry the weight of the floor.

Doulton's System.—The system adopted by this firm, and largely used, consists of a flat arch formed of

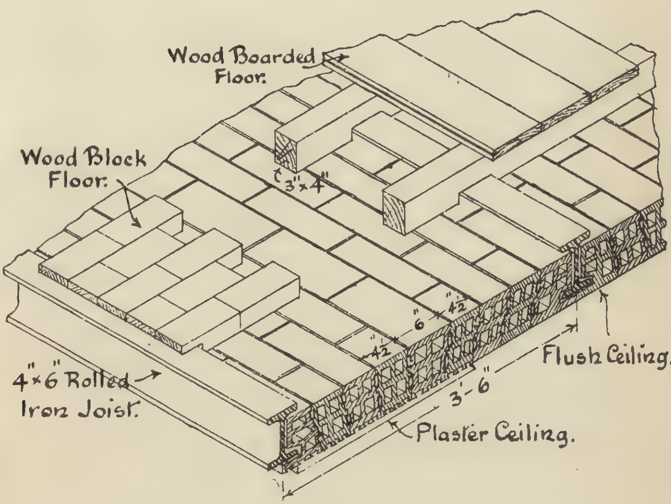


Fig. 374.

a number of hollow fire-brick voussoirs, these having diaphragms inside, as shown in figure 374, to strengthen them. Each voussoir is rebated, and has a dovetailed groove on the beds, to form a key for the cement joint; they also have dovetailed grooves on the under surfaces, to form a key for the plaster. The blocks are supported at intervals of about 3 feet 6 inches by rolled iron joists, the springers are made to envelop the bottom flange of the

joists, and thus to effectually protect the ironwork. The top may be covered in concrete with the surface floated in cement, or a wood-block floor may be fixed to it, or the concrete may be omitted and wood joists and a wood floor laid. The voussoirs are made of a special fireclay, which is not affected by great heat nor when suddenly cooled. The arches are constructed on centres, and when completed the joints are grouted with cement.

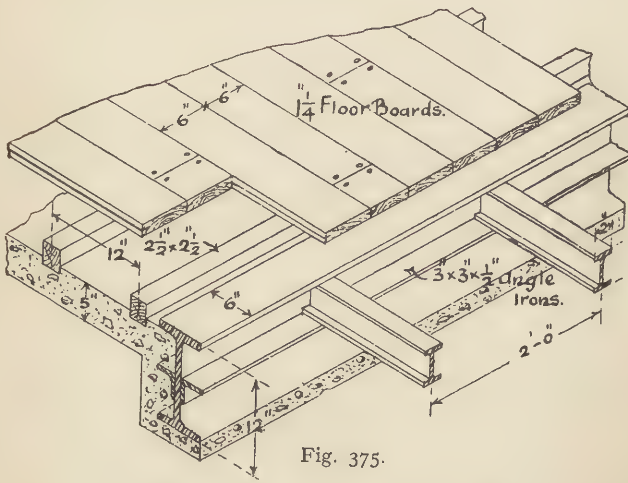


Fig. 375.

It is claimed for this system that the flooring may be laid and the plaster ceiling applied simultaneously.

Concrete and Steel.—In this method rolled steel joists of a section varying with the spans—but for 16 feet opening about 2 in. × 4 in.—are placed about 2 feet apart, from centre to centre, as shown in figure 375. To bridge the space, centering is suspended by hangers from the steel joists above, and coke breeze concrete is poured in between the joists. When this is set, the centering is removed and the soffit plastered, the plaster being applied to the surface. In

pouring in the concrete, the centering should be kept a short distance below the joists, which are then protected; this also prevents the iron showing through the plaster. Where the floor surfaces are large and main girders have to be employed, the latter are completely enveloped in concrete, as shown in figure 375; a box is constructed and supported about the bottom of the girder, and kept at least 3 inches away from it at every part, and in this the concrete is poured. The usual practice now is to place open wide meshed expanded metal or wire netting about the girder, blocked out from the lower flange to bind the concrete about the girder and prevent any portion of the concrete falling should it become detached. This method of flooring is easily applied, is light and fire-resisting, and useful for fixing purposes. The upper surface may be floated in cement, or have wood blocks, or joists and flooring. If the latter method be adopted, the joists are usually placed at right angles to the iron joists, being cut over them and bedded for about $1\frac{1}{2}$ inches in the concrete. In some cases the floor boards are nailed to the concrete direct, but such floors do not effectively prevent the passage of sound.

Dennet and Ingles.—This system, which has been extensively employed, is in many respects similar to that last described. Larger rolled steel joists are usually adopted, placed at distances of about 4 feet apart; the joists are completely enveloped in the concrete. The concrete, which is the speciality about this system, has, it is supposed, sulphate of lime or gypsum for its matrix, the aggregate consisting of broken bricks. The upper surface may be finished off in a similar manner to the preceding system.

Titancrete.—This system consists in covering the opening to be bridged with two systems of rolled steel joists, placed diagonally between the walls, one directly above the other

and in the opposite direction. The two systems are then enveloped in concrete, composed of cement and granite chippings. It is claimed that in this floor the rigid concrete prevents the steel from twisting when heated, and that the interlacing of the steelwork gives tensional strength to and prevents the disintegration of the concrete when heated and suddenly cooled. Columns are constructed with this material, being formed of bands of steel bent to a helical form and running in opposite directions, the pieces being riveted at the crossings. This is filled with a core, and the surface covered with concrete, thus making a solid steel and concrete column.

Measures' System.—The system adopted for many years by Messrs. Measures Bros. consisted of a number of main girders, to the webs of which angle irons were riveted for the support of smaller rolled iron joists. These latter were enveloped in concrete. Above this, wood joists were bedded to fix the floor boards, and in other respects this system is similar to the concrete and steel method already described. The plaster for the ceilings was applied directly to the underside of the concrete, and to prevent the iron showing through the plaster, Roman cement, which adheres well to iron, was placed directly on the underside of the joists.

Lindsay's System.—There are two systems adopted by this firm, both consisting of iron and concrete. One particular characteristic is that the aggregate of the concrete is of pumice stone. This renders the floors so constructed lighter than any other similar fire-resisting floor.

The first system, as shown in figure 376, is recommended for residential buildings, and consists of a number of rolled steel joists, the area of the section of which, and their distance apart, varying with the span. The girders

are connected by light steel rods about $\frac{3}{8}$ inch diameter, which are interlaced about the same in a manner analogous to herring-bone strutting in wood floors. The rods are placed about 1 foot 6 inches apart. They are strained tightly alternately above and below each joist, and are secured at their ends to the joists nearest to the wall. The whole of the steelwork is then entirely embedded in the concrete. The advantages claimed are, that the steel rods

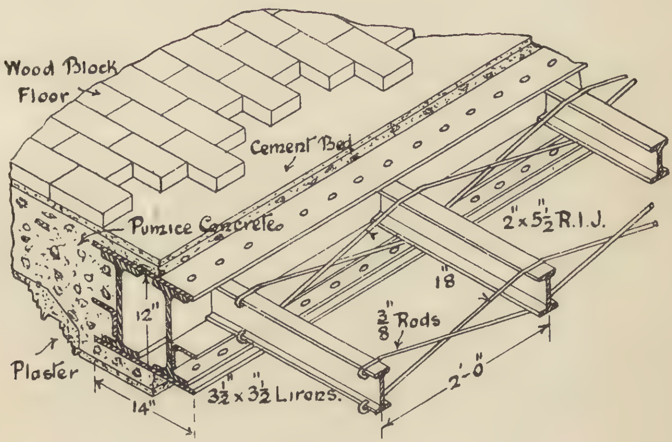


Fig. 376.

truss the floor, adding rigidity to the same, and distributing the effects of any concentrated load over the whole of the floor. The rods also prevent the concrete from flying when heated and suddenly cooled. Where any main girders occur they are entirely enveloped in concrete, as shown in figure 376. The plaster for ceiling is applied directly to the surface of the soffit. The floors may be wood block, or sleepers may be secured by nailing to the concrete and floor boards fixed to them, or they may be floated in cement.

The wood sleepers are often omitted in this form of floor, and screeds of pumice concrete are run across the surface of

the floor, to which the boards are nailed. This reduces the possibility of dry rot occurring.

Fire-resisting roofs of any shape, and domes, are also constructed on similar principles consisting of a light framework of iron or steel joists, interlaced with light iron rods, the whole being embedded in pumice concrete.

The second system, as shown in figure 377, constructed by Messrs. Lindsay, consists of a number of steel troughs or

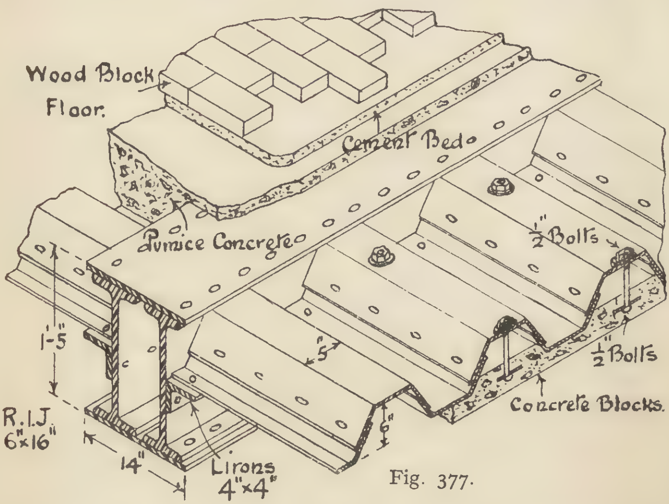


Fig. 377.

channels, the sides of which are splayed internally to an angle of 120°, and are much thinner than the bottoms of the troughs. These channels are alternately inverted, and are riveted together at the sides, as shown in figure 377. They thus form a peculiar kind of girder, having the greatest amount of metal as far as possible from the neutral layer, and being riveted at that part where the cross stress is theoretically *nil*. They form a continuous homogeneous layer of steel over the whole surface, and any stress exerted in one part is distributed over the whole. This steel decking is covered with

a layer of pumice concrete, on which the cement, asphalte, or mosaic flooring is laid, or the sleepers for a wood floor are bedded or fixed. The lower surface of the troughs can be protected, if required, by slabs of pumice concrete hung to the soffit by bolts, and on this the plaster is laid; or wood battens can be bolted to the underside of the troughs, and lath and plaster fixed in the ordinary way. The spaces on

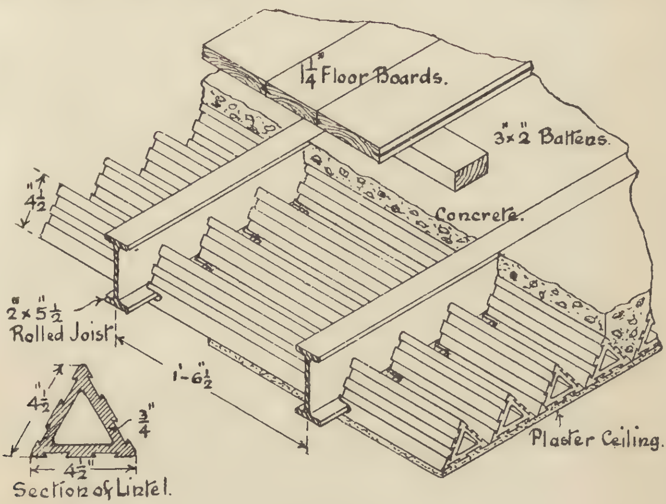


Fig. 378.

the underside of the troughs can be utilized to contain gas or water pipes, electric wires, or be used for ventilating purposes.

These floors are useful for warehouses, railway stations, bridges, or wherever great weights have to be supported.

Cast-iron stanchions, or steel columns, constructed of six pieces of steel troughing riveted together, as shown in figure 520, *Elementary Course*, are also rendered fire-resisting by filling the interior with a core of pumice concrete, and encasing them on the exterior with the same

material, the surface of which can be finished with cement, or any method of ornamental plastering, to any design.

Homan and Rodgers.—These well-known and extensively used floors consist of rolled steel joists, placed at intervals of about 1 foot $6\frac{1}{2}$ inches from centre to centre, on the

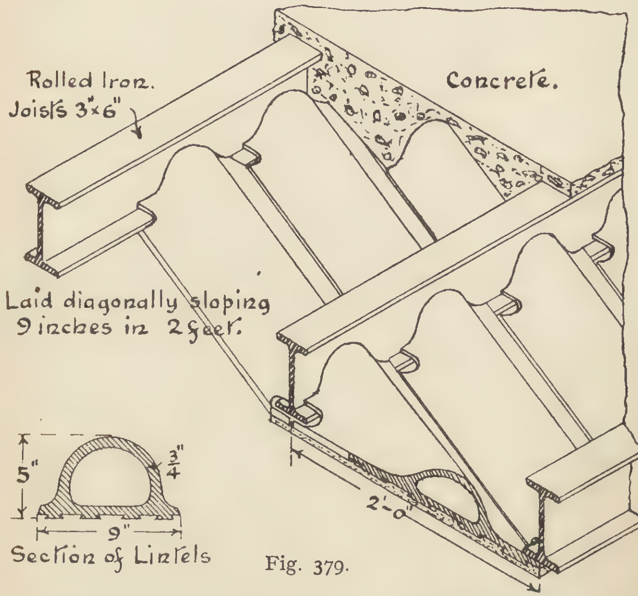


Fig. 379.

bottom flanges of which purposely made hollow bricks, or lintels, triangular in section and about $4\frac{1}{2}$ inches width of side, are placed. The bricks have an incision at both ends to fit over the bottom flange of girder, thus encasing the latter and protecting it on the underside. The lintels are placed side by side and close together, thus forming a centering for the concrete which is bedded over them to the level of the top of the girder, as shown in figure 378. The upper surface may be finished by any of the methods

previously described. The lintels on their under surface have dovetailed shaped grooves, which form a key for the plaster, this being applied direct. It is claimed for this method of flooring that they are eminently fire-resisting and nearly noiseless, the sound vibrations being intercepted in passing through the concrete, brick, and plaster, and the air space; all these mediums being of varying densities.

Fawcett's.—This method consists of rolled steel joists of sections to suit the span, placed at 2 feet centres. Between these are placed tubular lintels, as shown in figure 379, manufactured from red or chimney-pot clay, these being the special features in this system. The lintels have an incision at each end to enclose the bottom flange of the joists, and are placed with their diagonals at right angles to the latter; an air space of about ½ inch is left between the under side of bottom flange and the lintel. This may be used for the conduction of air for ventilating purposes, in which case the lintels in the several bays must be kept linable, and air bricks inserted in the walls in the end bay. The lintels, to fit the square ends of the bays, are cut during manufacture. These are termed splits, and, where they only bear on one joist, have a bearing fillet cast on one side to allow them to obtain a bearing on the lintel next to them. The lintels in the end bays obtain a bearing of about 2 inches on the side of a horizontal chase, arranged in the wall.

When the lintels are in position, specially prepared cement concrete is filled in over them, enclosing the girder and taking a direct bearing on the bottom flange of the joists. The lintels form a permanent centering, and their large size considerably reduces the amount, and, consequently, the weight of the concrete.

The flat bottom of the lintel completely encases the bottom flange of the joists without being in contact with it. It also has a number of longitudinal dovetailed grooves to form a key for the plastering. These floors are very

effective for fire-resisting purposes, and are very extensively used.

Concrete Stairs.—Concrete stairs are now extensively used in fire-resisting structures where it was once customary to use stone. They are constructed upon flat centres, strutted up to the pitch of the stairs, having wood moulds to form the risers, and also to the free ends where a hanging stair is being formed. To form moulded nosings, their reverse must be part of the wood riser moulds. The front of the riser and nosing is filled in against the mould first, in neat cement or fine stuff. The coarse concrete, forming the body of the stair, is then put in, and the surface forming the tread floated direct. Great care should be taken that the riser and tread are formed as stated when the body of the tread is cast. If floated on when the latter is set, they invariably chip off and scale away after being in use for a short time.

If hanging stairs of a width not exceeding 2 feet 9 inches are used, or where stairs supported at both ends by a wall are employed, the stairs may be constructed of concrete only; but if hanging stairs of a width exceeding that stated above are used, it is wise to employ ironwork to endow them with a certain amount of tensional strength.

The concrete steps should be run at least $4\frac{1}{2}$ inches into the supporting walls. Where the concrete is supplemented by ironwork, one of the three following methods is usually adopted:—(1) Small inverted T irons, having one end pinned into the wall, and projected as cantilevers, one being arranged so as to be enclosed by each step. (2) The ends of these ⊥ irons are turned up square, and are all connected by a piece of light bar iron, to which they are screwed. This acts as a string, and forms a light iron framework, binding the ends of all the steps together. The ironwork is enveloped by the concrete when the steps

Fig. 380.

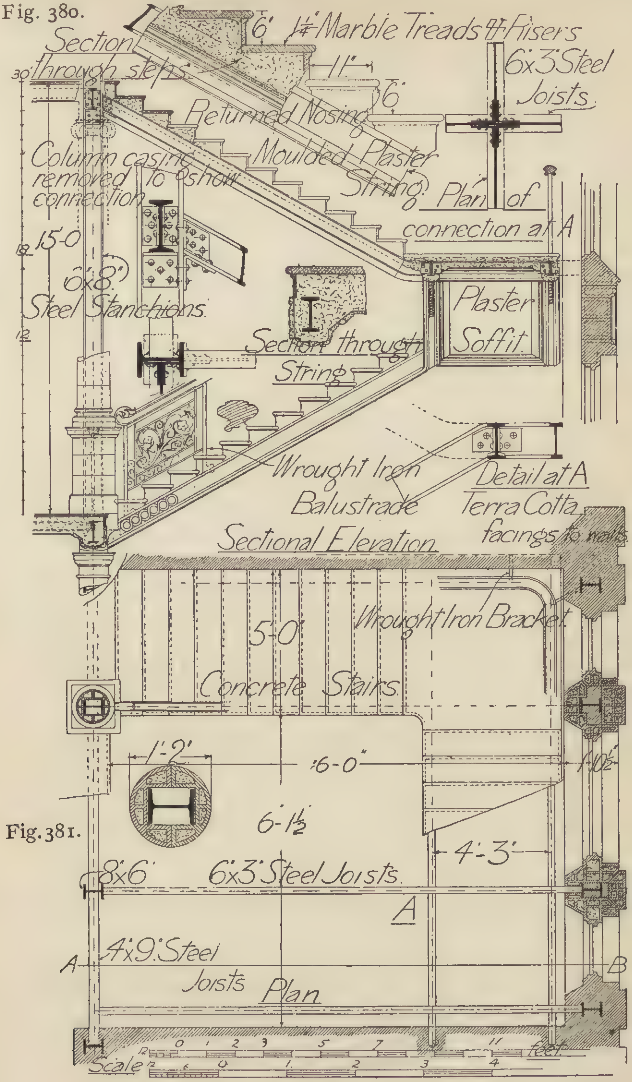


Fig. 381.

are cast; this method forms a very strong stair. (3) Iron joists are fixed to support the outer ends of the stairs, being bent to the shape of the soffit, and having the ends pinned into the walls, no other iron members being used.

Figures 380 and 381 show the construction of a staircase built upon this system.

Fire-resisting Solutions.—Where a large amount of exposed timber is used in the interior of buildings, it is wise to cover the same with a fire-resisting solution, of which there are two kinds in general use—tungstate of soda and asbestos paint. These two have the property of retarding the action of fire to a considerable degree. Tungstate of soda has resisted the action of fierce fires for as long as twenty minutes. Asbestos paint is reputed to excel tungstate of soda in fire-resisting properties. A fire that occurred in the Inventions Exhibition buildings was successfully resisted by the covering of asbestos paint.

Bye-Laws affecting Fire-resisting Materials.—The London County Council consider for the purposes of their Act the following to be fire-resisting materials:—

1. Brickwork constructed of good bricks, well burnt, hard and sound, properly bonded and solidly put together;

(*a*) With good mortar compounded of good lime and sharp clean sand, hard clean broken brick, broken flint, grit, or slag; or

(*b*) With good cement; or

(*c*) With cement mixed with sharp clean sand, hard clean broken brick, broken flint, grit, or slag:

2. Granite and other stone suitable for building purposes by reason of its solidity and durability:

3. Iron, steel, copper:

4. Oak and teak and other hard timber when used for

beams or posts or in combination with iron, the timber and the iron (if any) being protected by plastering in cement or other incombustible or non-conducting external coating;

In the case of doors—Oak or teak or other hard timber, not less than 2 inches thick;

In the case of staircases—Oak or teak or other hard timber, with treads, strings, and risers, not less than 2 inches thick:

5. Slate, tiles, brick and terra-cotta when used for coverings or corbels:

6. Flagstones when used for floors over arches, but not exposed on the underside and not supported at the ends only:

7. Concrete composed of broken brick, stone chippings or ballast, and lime cement or calcined gypsum when used for filling in between joists of floors:

8. Any material from time to time approved by the Council as fire-resisting.

CHAPTER XI.

REINFORCED CONCRETE OR FERRO-CONCRETE.

Definition.—Constructions of concrete and steel, in which the materials are so disposed as to bring into action the highest stress-resisting properties of each, are known as reinforced concrete, sometimes as ferro-concrete or armoured concrete.

Object and Advantages.—The advantages of this method of construction consists in its great measure of fire-resistance, as instanced by several examples where structures of this character have resisted fierce fires with little injury; its economy in construction (about 15 per cent. less than in other materials doing similar work) and its monolithic character, which in cases of soft and unreliable soils is a great advantage, and from the imperishable nature of its materials as disposed—an eternity of duration is claimed for it by its chief exponents.

Preservation of the Steel.—It has been established that if iron or steel bars are properly bedded and surrounded with Portland cement concrete of correct constituents and proportions there is not only no tendency to rust, but the cement coating actually preserves the iron or steel. It is supposed by the users of ferro-concrete that a coating of a ferrite of calcium is formed which protects the steel from further action.

It is important to thoroughly ram the concrete about the reinforcements to ensure them being thoroughly coated, also it is advisable to cover them with a wash of neat cement before bedding.

Expansion of Concrete and Steel.—Secondly, with reference to the expansion of the two materials, it has been found that the difference of the co-efficients of expansion between cement concrete and steel is practically a negligible quantity, their values, according to Professor Pence, Purdue University, U.S.A., being for Portland cement concrete ·0000055 expansion for 1° Fahr., and for steel, according to Rankine, ·0000069, the difference in length in 100 feet lengths of each for 1° Fahr. being ·00014 feet, therefore for a difference of 100° Fahr. ·014 feet or ·168 inches. This defect is in some systems minimised by the twisting of bars of rectangular sections or bars with corrugated surfaces.

Adhesion of Concrete to Steel.—The adhesive value of the concrete to the steel varies from 250 to 570 lbs. per inch; the value for properly prepared concrete on a clean steel bar covered with a Portland cement wash may be taken as 500 lbs. per square inch.

These three properties of non-rusting, similarity of the values of the co-efficients of expansion, and the non-slipping of the reinforcement through the concrete, enable the concrete and steel to be combined so as to constitute homogeneous structures in which advantage is taken of the best stress-resisting qualities of each material, steel having a high resistance to tension and concrete to compression.

Concrete.—The value of reinforced concrete depends entirely upon the prudent selection and careful mixing and disposition of the concrete. The best aggregates are shingle or broken sandstone—limestone must be rigorously excluded on account of its change under the action of heat. The shingle or gravel must be clean and screened from all sand

to enable the correct proportions to be obtained. The mortar or binding material must be in quantity sufficient to completely fill all the voids between the pieces of the aggregate. The quantity of the mortar required may be determined by filling a measure with the screened aggregate, then pouring in water till the measure is full (the quantity of the water is the measure of the void), to this an allowance of about 50 per cent. must be made for shrinkage in mixing of the dry materials, Portland cement and sand. A coarse, clean sand is necessary, and the gravel should, in small work and about reinforcements, pass through meshes, from $\frac{1}{8}$ to $\frac{3}{4}$ inch (never having all of one size). The cement used is the best Portland—see chapter on Limes and Cements. When Thames ballast is employed the measured proportions usually work out at 1 Portland cement, $1\frac{2}{3}$ sand, and $3\frac{1}{3}$ ballast.

The mixing should be thorough and just enough water being used to bring the concrete to a plastic state. Concrete is more uniform in character when mixing machines are employed than when the compound is mixed by hand.

The concrete should be thoroughly rammed and worked about the reinforcements and for the maximum of efficiency wherever possible with a minimum thickness of 2 inches, special tools being devised for this purpose; also it must be thoroughly rammed on the surface.

Reinforcement.—Mild steel is the material used for the reinforcements, owing to its high value of tensile resistance; it should satisfy the tests for strength and ductility as given in the article on Steel. Several sections are employed, but the circular section, owing to its greater adaptability and concentration of its mass, is most suitable; some sections are indented or twisted to prevent slipping of the bar through the concrete, but the high adhesive resistance of good cement concrete to steel renders this unnecessary.

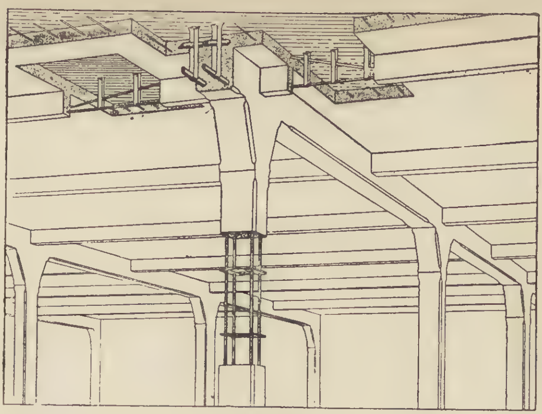


Fig. 383.

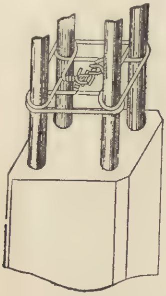


Fig. 382.

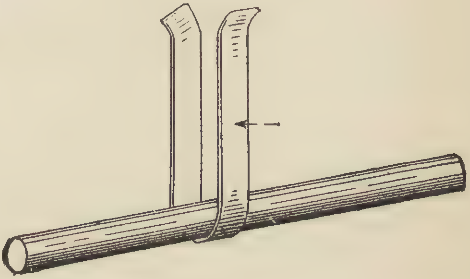


Fig. 385.

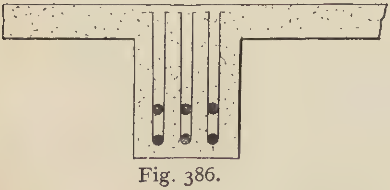


Fig. 386.

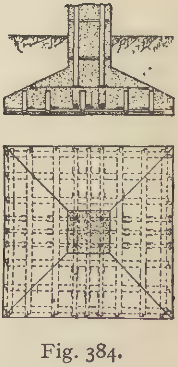


Fig. 384.

The value of this adhesion varies from 250 to 570 lbs. per inch; let the value of the ultimate resistance of mild steel be taken as 60,000 lbs. per square inch, then the length of steel surrounded by concrete for the adhesion to equal the tensile resistance

$$l \times 2\pi r \times A = S f_t.$$

l = length; A = adhesive resistance, say 500 lbs.; S = sectional area of bar; f_t tensile resistance = 60,000,

$$l = \frac{S f_t}{2\pi r A} = \frac{\pi r^2 \times f_t}{2\pi r \times A} = \frac{r f_t}{2 A} = \frac{r \times 60{,}000}{2 \times 500} = 60 r = 30 d.$$

therefore if the diameter = $\frac{1}{2}$ inch, the length required for the adhesive and tensile resistances, with the values given to be equal would be 15 inches.

To ensure the perfect contact of the concrete to the steel, the latter should be free from all scale and receive a wash of Portland cement before being embedded.

Electrolysis.—The gradual corrosion of steel from electrolysis due to the action of vagrant electric currents is a danger that with proper electric light and power installations ought not to be very great at any time, and this would be reduced to a minimum if an earth test were made every six or twelve months; any growing fault would be detected and could be put right.

Compressional Resistance.—The strength of a reinforced pillar in compression may be taken as the strength of the sectional area of the steel plus the strength of the concrete, and as the ultimate resistance to compression of steel and concrete is 60,000 to 2,000 lbs. per square inch respectively, that is in the ratio of thirty to one, the steel to obtain the maximum moment of inertia should be placed as far as practically possible from the neutral axis of the pillar, care being taken to have every steel section surrounded by at least two inches of concrete. Taking a pillar of the Mouchel (Hennebique) construction these may be considered as pillars fixed at both ends, and it would be well to

test these for the value of their resistance by the formula for compression given in the chapter on Pillars, viz., $p = \dfrac{f}{1 + a\dfrac{l^2}{r^2}}$, for a pillar of concrete $f_c = 350$ lbs.; $a = \dfrac{1}{\frac{2}{3}f} = \dfrac{3}{700}$, l = length in inches between the fixings; r = radius of gyration, p = value per square inch of sectional area, P = total resistance = S p, when S = total sectional area. From this may be obtained the value of the resistance of a pillar in concrete.

Let it be considered advisable that half the load be carried by the concrete and half by the steel reinforcement, and the limiting distance of the steel reinforcement is determined by the condition that it must be surrounded by two inches of concrete. Let it be required to determine the strength of a pillar, 12 inches square in section and 12 feet in length, fixed both ends, then using the formula from the chapter on Pillars.

$$p = \frac{2000}{1 + a\dfrac{l^2}{r^2}},$$

$$p = \frac{2000}{1 + \dfrac{1}{\frac{2}{3} \text{ of } 2000} \times \dfrac{144^2}{12}}$$

$$p = \frac{2000}{1 + \dfrac{3}{4000} \times 1728}$$

$$p = \frac{2000 \times 4000}{9184}$$

The area of the section is 12 in. × 12 in.

$$\therefore \mathrm{P} = \mathrm{S}\,p = 144\,p.$$

From the table in the chapter on Pillars when $\dfrac{l}{d} = 12$, the factor of safety 4·84 is given.

$\therefore$ for safety $\mathrm{P} = \dfrac{\mathrm{S}\,p}{4{\cdot}84} = \dfrac{144 \times 2000 \times 4000}{9184 \times 4{\cdot}84} = 25{,}917$ lbs. carried safely by the concrete only.

To this is to be added the load carried safely by the steel.

The area of the steel will therefore be area of concrete over thirty $= \frac{144}{30} = 4 \cdot 8$. Let this be made up of 4 rods, then area of each rod $= \frac{4 \cdot 8}{4} = 1 \cdot 2$, and diameter of each rod

$$= \sqrt{\frac{1 \cdot 2}{\cdot 7854}} = 1 \cdot 236.$$

The reinforced pillar will therefore safely support, $2 \times 25{,}971 = 51{,}834$ lbs. $= 23 \cdot 14$ tons.

It is probably true to say that the pillars made by the Mouchel Hennebique patent system, owing to their careful selection, proportioning and disposition of the materials due to the knowledge gained by vast experience, could be safely trusted to carry a greater load.

Figures 382, 383 and 384 give views of the formation of the section and a perspective view and base of the junction of the pillar with the superimposed beam.

Tensional Resistance.—The value of the ultimate tensile strength of Portland cement concrete one to six is about 250 lbs. per square inch. This being so low relative to the steel, which may be taken as 60,000 lbs., it may be disregarded as resisting tensional stress, and only looked upon as a clothing for the steel which must be calculated to withstand the whole of the tensional stress.

Transverse Resistance.—Generally the compressional resistance of a beam is offered by the concrete only, advantage being taken of its comparatively high resistance to that stress; the tensional resistance is calculated in most cases to be taken by the steel only; although the concrete offers a certain tensile resistance, it is unwise to take advantage of it, for if the lower portion of the beam fail or crack by shearing or deflection, the whole of the stress would have to be taken by the steel, and the margin of safety is reduced by the amount originally computed to be taken by the concrete.

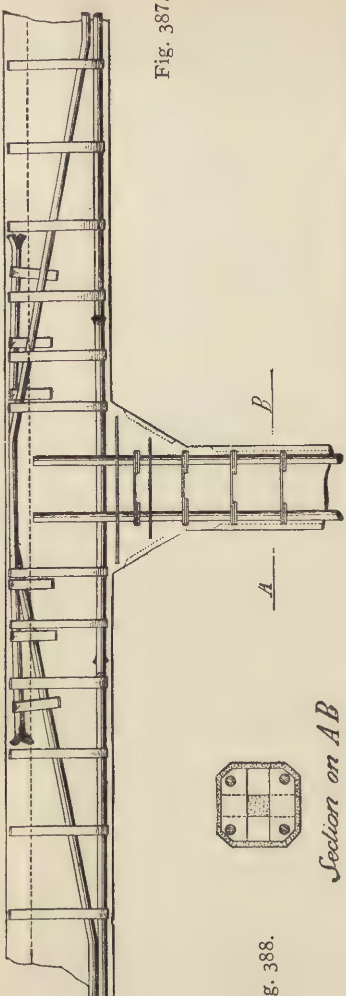


Fig. 387.

Fig. 388.

Section on AB

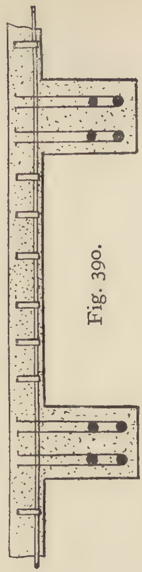


Fig. 390.

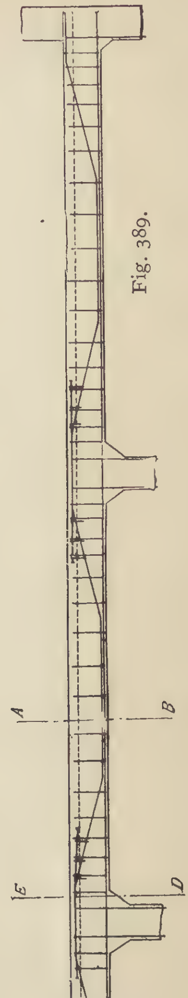


Fig. 389.

The formula for computation of ferro-concrete beams may be deduced from that described in the chapter on Girders as follows :—

$$(1)\ M L = M R = \frac{f_0 I}{\delta}$$

In a rectangular beam of pure concrete the resistances in tension and compression are as 1 to 10 respectively, the depth of the fibres in compression to those in tension will then be as 1 to 3·162; but if steel reinforcements be placed in the tensional portion of the beam, if the neutral axis be supposed stationary, then the depth of the lower portion may be modified according to the quantity and position of the reinforcement.

Example—A reinforced concrete beam 2 ft. deep, neglecting any advantage of the tensional resistance of the concrete. Determine the proportions; let the safe resistances of concrete in compression and tension be 500 and 50 lbs. respectively, and the safe tensile resistance of mild steel as 15,000. Let it be required to support a distributed load of 20,000 lbs. over a span of 20 ft. Then

$$(1)\ M L = \frac{f_0\ I}{\delta}$$

the stress f_0 per unit area on extreme fibres of compressional portion of beam may be determined thus

$$(2)\ M L = \frac{f_0\ 2\ \frac{b\ x^3}{3}}{x} = f_0\ \tfrac{2}{3}\ b\ x^2$$

for a beam supported only load distributed as in example,

$$(3)\ \frac{W\ l}{8} = f_0\ \tfrac{2}{3}\ b\ x^2$$

$$(4)\ f_c = \frac{W\ l}{5{\cdot}3\ b\ x^2}$$

Let F_0 = the summation of all the resistances, and the

area $b\,x$ of No. 4 formula be supposed concentrated at a point in the horizontal plane of the reinforcement, then as the average stress on the fibres will be $\frac{f + o}{2}$ then

F_o = the mean stress × area of compressional portion.

$$(5) \quad = \frac{f_o + o}{2} \, b\,x$$

$$(6) \quad = \frac{W\,l \times b \times x}{5{\cdot}3 \times b \times x^2 \times 2} = \frac{W\,l}{10{\cdot}6\,x}$$

$$\text{The area A of reinforcement} = \frac{F_o}{f_t} = \frac{20{,}000 \times 240}{10{\cdot}6 \times 12 \times 15{,}000} = 2{\cdot}51 \text{ inches.}$$

Let this area be distributed between four round bars, then the area of each rod $= \frac{2{\cdot}51}{4} = {\cdot}6275$, and the diameter

$$d = \sqrt{\frac{{\cdot}6275}{{\cdot}7854}} = {\cdot}893 \text{ ins., say 1 in.}$$

The breadth of the compressional areas may be obtained as follows :—

$$(3) \quad \frac{W\,l}{8} = f_c \, \tfrac{2}{3} \, b\,x^2$$

$$(7) \quad b = \frac{W\,l}{5{\cdot}3\,f_c\,x^2} = \frac{20{,}000 \times 240}{5{\cdot}3 \times 500 \times 10^2}$$

$$b = 18 \text{ inches nearly.}$$

Shearing Stress.—The tendency of the shearing stresses is to cause failure by tensional and compressional stresses induced along lines of 45° to the tensional flange as explained in the chapter on Girders. The failure in reinforced beams usually takes place in a direction at right angles to the tensional lines of force at 45° to the tensional flange. This must be provided for by placing steel members connecting the bottom with the top flanges. Theoretically, these would therefore best be placed at the angles of 45°. If the arrangement be considered as the bars in a lattice girder, these steel members would be doing the duty of the tensional bars, hence they

should have the similar direction, whilst the concrete, owing to its relatively great compressional value, does the work of the compressional bars which they displace, hence these shearing or lattice bars should be proportioned to the intensity of the shearing stress in any part of the beam, which actual value may be obtained from a stress diagram similar to those obtained for the bars in a lattice girder as shown in figure 325, or where for practical reasons they are placed vertically, as shown in figures 385 and 389, being generally in this position easier to fix, the stresses may be obtained from a diagram similar to that shown in figure 323.

Ferro-concrete Building.—It is not unthinkable that in the art of building it would be possible if all concrete mixers were chemists and all supervisors scientists, for a building in reinforced concrete to be evolved by the average builder, but in the present state of building practice and for several years to come, till all engaged in these building operations are more thoroughly cognisant with the properties of this new composite material, it would undoubtedly be at a great risk and with almost a certainty of being more expensive than building with the ordinary materials, hence it is undoubtedly wise to entrust any important work in this direction to specialists, as is often done in the installation of ventilating, heating and electrical apparatus, and it is generally found by following this that a saving of as much as 15 to 30 per cent. may be effected with more reliable efficiency. The following diagrams illustrate the construction of pillars, beams, floors, piles, foundations, &c., representing the Mouchel Hennebique practice, whose patent methods, embodying simplicity, efficiency, and durability, have been employed extensively in this country and in many parts of the world with great success.

Piles.—Ferro-concrete is eminently suitable for piles and any position where any alternation of wetness and dryness

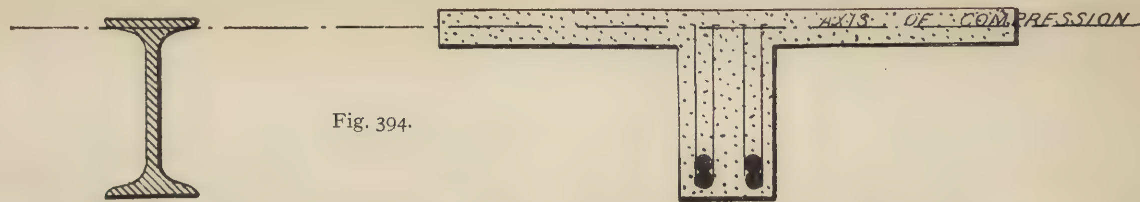


Fig. 394.

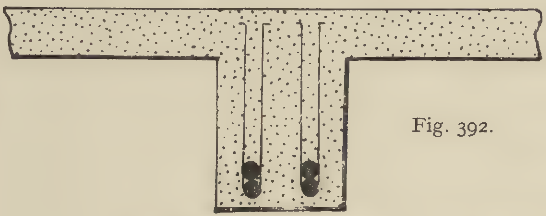


Fig. 392.

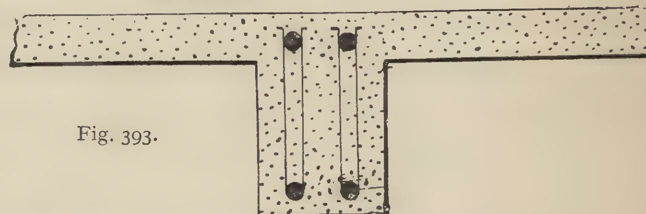


Fig. 393.

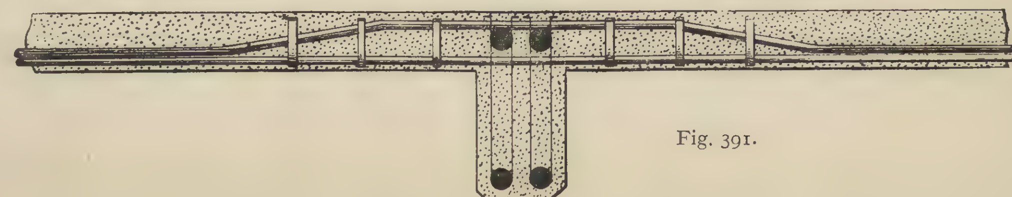


Fig. 391.

which is so destructive to timber, occurs, also where erections would be subject to the ravages of insects. Both guide and sheet piles are now largely used. These piles lend themselves admirably to be lengthened during the process of driving should this be found necessary. Ferro-concrete piles 14 in. × 14 in. have been calculated to carry safely 80 tons, the ultimate resistance being 400 tons.

Floors.—These are constructed, as shown in figure 383, similarly to the triple joisted system of wood flooring, as explained in the *Elementary Course*, having primary girders, secondary girders and floor slabs. The greatest economy is effected when the floor slabs are square in plan, and such that they may be considered fixed along their four edges.

Figure 394 is a section of a ferro-concrete girder at the centre of its bearing, showing the upper fibres of the concrete beam and the floor slab arranged to form the compressional flange, whilst the tensional stresses are resisted by the steel reinforcement plus the adjacent concrete.

Figures 386 to 394 show the disposition of the reinforcements to economically resist the tensional stresses, the girders being designed as beams fixed at ends under a distributed load.

Figures 386 and 392 to 394 give cross-sections showing the reinforcements at different parts of the lengths of the beams.

Foundations.—The construction of reinforced foundations for soft soils are constructed on similar principles to those described for floors.

For light buildings, the 9 inch slab of concrete often specified may be greatly strengthened by the introduction of lattice work of light steel bars from 1 to 3 feet apart and about 3 inches from the bottom.

Walls.—These are constructed on the pier and panel system, the piers acting as pillars to support the various

floors and roofs of the buildings. The panels form the screens between the piers. The reinforcements in the screens are usually placed in the centre.

Roofs and Arches.—These, if flat or having an inclination, are constructed on similar principles to floors. If vaulted, main arches are constructed at intervals, the intervening vaulted surface being reinforced with interlacing bars of small diameter, or if the vaulted space be of small span, expanded metal may be used as the reinforcement.

Joints.—The compressional joints are butted and enclosed in a socket or thimble which serves to retain the axes of the lengthened members in one straight line till the concrete has set; each joint is also assisted by two flitch bars of circular section $\frac{5}{8}$ inch diameter, with fish tail ends.

The tensional joints are made by lapping, the length of the lap being such that the adhesive resistance equals the tensional resistance. The joints should be made as near as possible to that part of the beam where the bending stress is at the minimum. All welding of joints should be avoided owing to the liability of injuring the steel and the uncertain value of the connection.

CHAPTER XII.

ROOFS AND ROOF COVERINGS.

Continued from Elementary Course.

Roof Trusses.—The methods of calculating the magnitude of the stresses in roofs have been given in the chapter on Statics, and the construction of roofs has been dealt with somewhat at length in the *Elementary Course*, and the following will only be mentioned here:—Mediæval, and curved rib trusses; and the calculations for the members, and the riveted and pin joints of steel trusses.

Mediæval Trusses.—It may be convenient to trace the development of the trusses used in the mediæval roofs under five headings. The principle throughout is to use timber to resist compression and transverse stresses, and to reduce the tensional members to a minimum.

(1) Roof trusses, the outline of which was similar to the couple-close truss, figure 395, and the horizontal member of which was supported along its entire length by masonry or brickwork in its turn, supported by a stone arch, the abutments of which were the main walls; and having one central, vertical member in the truss under compression, this member being known as a crown-post.

(2) A truss of the outline of the collar-beam truss, figure 396, was placed instead of a couple-close truss, all other parts being similar to the first. This made it possible

for the arch in a similar sized building to be of greater height.

(3) The stone arch and wall under the truss of the first type was substituted by a timber arch, in the form of a pair of brackets, the curved struts and horizontal members performing the work of the arch and wall, as shown in

Fig. 395.

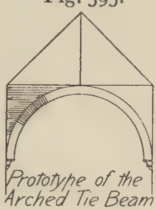
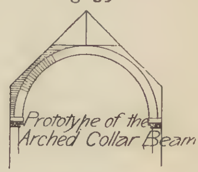


Fig. 396.



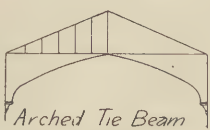


Fig. 397.

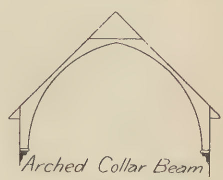


Fig. 398.

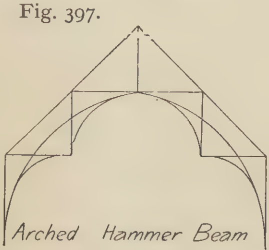


Fig. 399.

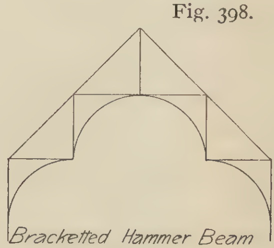


Fig. 400.

figure 397. This construction is known as the arched tie-beam. The strut members of the brackets were sometimes put in straight.

(4) In the collar beam type supported by a stone arch, the latter was in course of time substituted by wood, as shown in figure 398. Instead of the wood rib being under compressional stress only it is here also under transverse

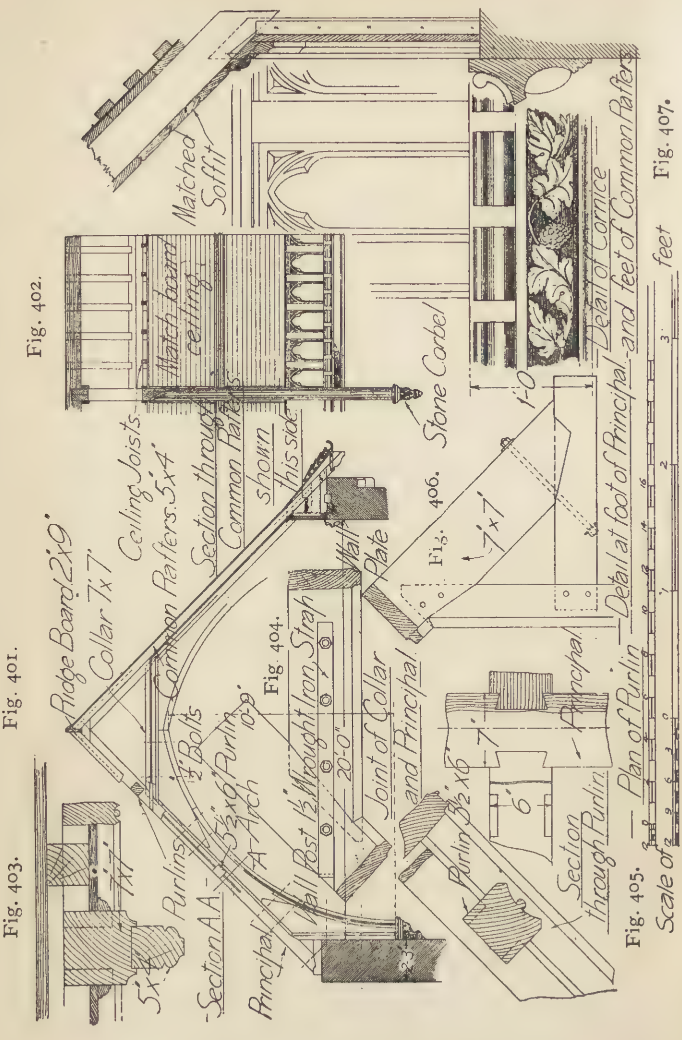


Fig. 401. Fig. 402. Fig. 403. Fig. 404. Fig. 405. Fig. 406. Fig. 407.

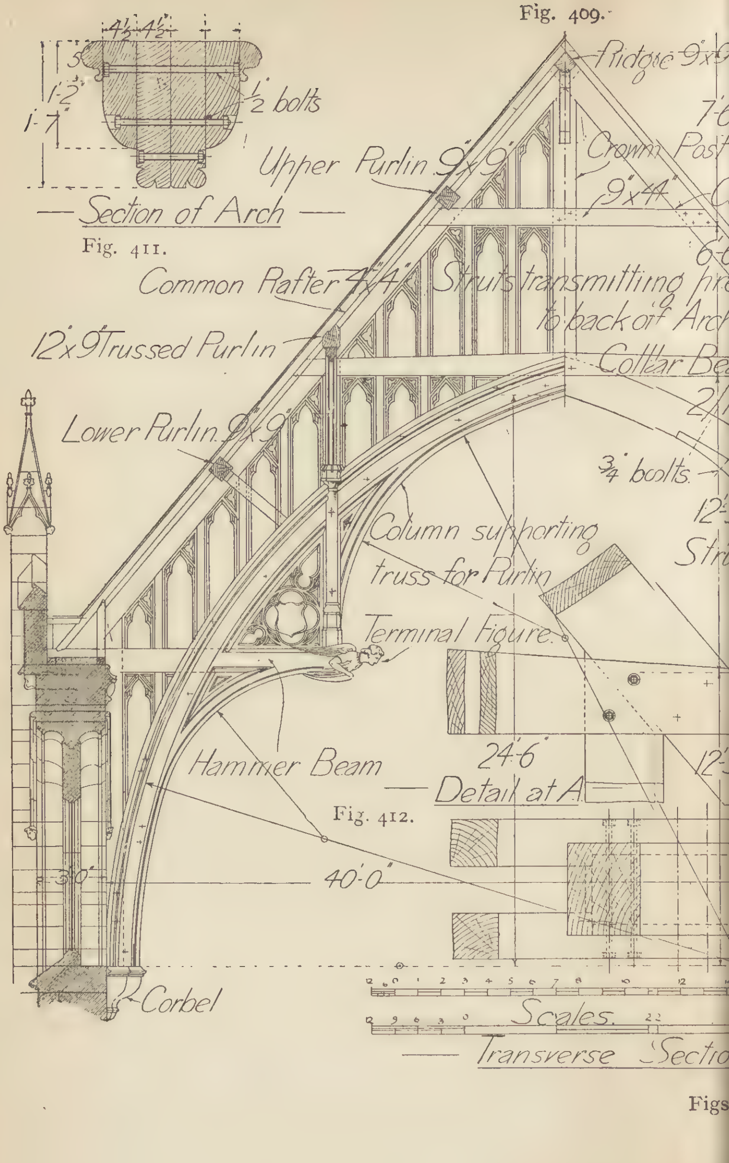


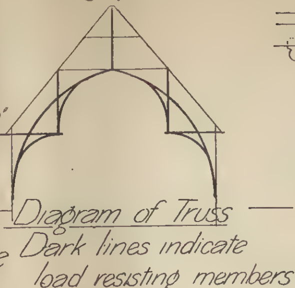
Fig. 409.

Fig. 411.

Fig. 412.

Figs.

Fig. 408.



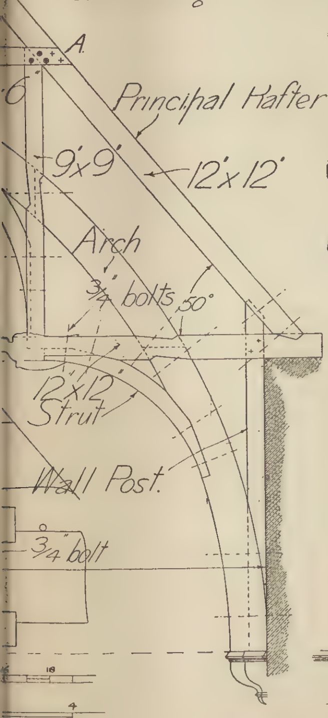
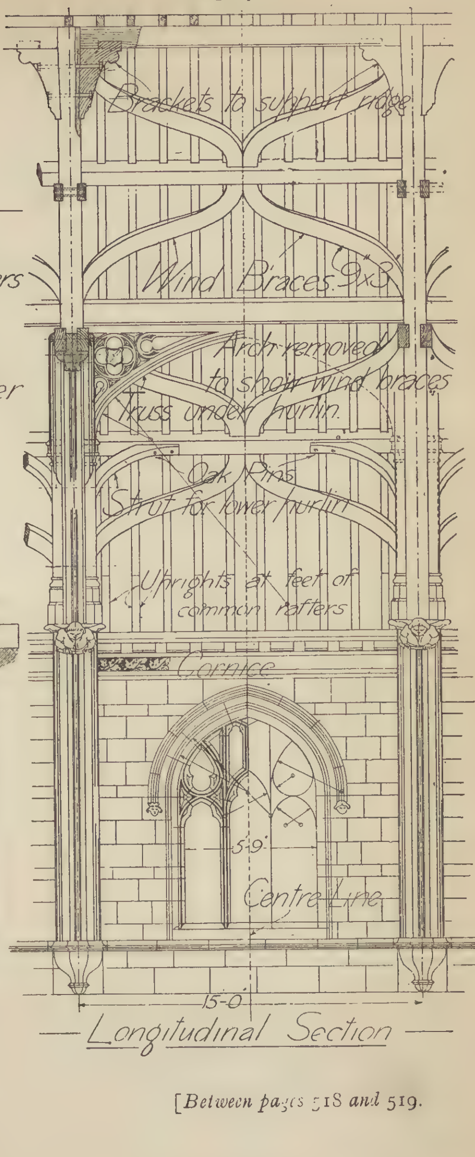


Fig. 410.



3—412.

[*Between pages* 518 *and* 519.

stress, being used as a gusset piece preventing the deformation of the joint between collar and principal and wall post and principal, and at the same time transmits the compressional stress at a great distance below the top of the wall, as shown in figures 401 to 407. This form of truss does not detract from the height of the chamber, the covering of which it supports, and is suitable for spans of about 20 feet.

(5) For larger spans than 20 feet the hammer beam principle is preferable. These are of two kinds, the arched and the bracketed, as shown in figures 399 and 400.

(*a*) Figures 408 to 412 show an example of the arched type. In this the main constructional member is the timber arch. This is formed from four pieces bolted together and moulded. The crowning moulding of the arch is simply an ornamental member. The tendency of an arch when loaded at the crown is to sink at the latter part and for the haunches to rise. In this type it is prevented by the insertion of a horizontal member known as a hammer beam projecting at the level of the foot of the principal rafter, to which the latter is framed, and an upright at the extremity of the hammer beam which triangulates the arch at that point; this tends to prevent the above-mentioned deformation. This combination is assisted by two struts, which further extends the influence of the former. The struts are usually curved, so that they may flow into the curve of the large arch, and thus prevent the appearance of anything approaching a broken or crippled curve, and giving the appearance of a cusped arch. The weight of the rafters and roof coverings is transmitted to the principal rafters by means of the purlins, the principal rafters transmit the weight to the arch through a number of vertical studs, the latter being tenoned to the principal rafters and the back of the arch. The ridge in this type usually consists of a heavy beam supporting the common rafters as shown. This is

supported on brackets secured to uprights termed crown posts, which transmits the weight to the centre of the arch. The spaces between these upright members are usually fitted with small cusped frames for decorative effect. The lowest purlins are stiffened by means of two struts usually curved, as shown in figure 410, the foot of the struts resting upon the back of the arch. The centre purlins are stiffened by means of a vertical wood arch, which spans the space between the two trusses and springs either from the back of the main arches or from a small column, as shown in figures 409 and 410, secured to the upright that rests upon the extremity of the hammer beam. This arch has its spandril invariably filled with tracery, which gives to the whole composition a very rich effect. The roof is stiffened longitudinally by means of members known as wind braces, which are placed against the underside of the rafters, and abut upon the principals. These are usually curved for effect.

The arch rests upon a stone corbel or the capital of a wall column at some distance below the top of the wall.

The increased unobstructed height of the chamber, obtained by trussing in this manner, adds greatly to the internal majestic appearance of the roof, but the rigidity of the framing depends to a large extent upon the immovability of the abutments.

(*b*) At a later period a similar type of roof to the above, omitting the arch, as shown in figure 400, was used. This alters the principle of the truss entirely, which now practically becomes two braced girders, tilted and butting against each other in the centre. The curved members of the brackets are now in tension, and their function could be better performed if they were straight. In other respects the constructional details are similar to the preceding example shown in figures 408 to 412.

Fig. 413. Fig. 417. Fig. 414.

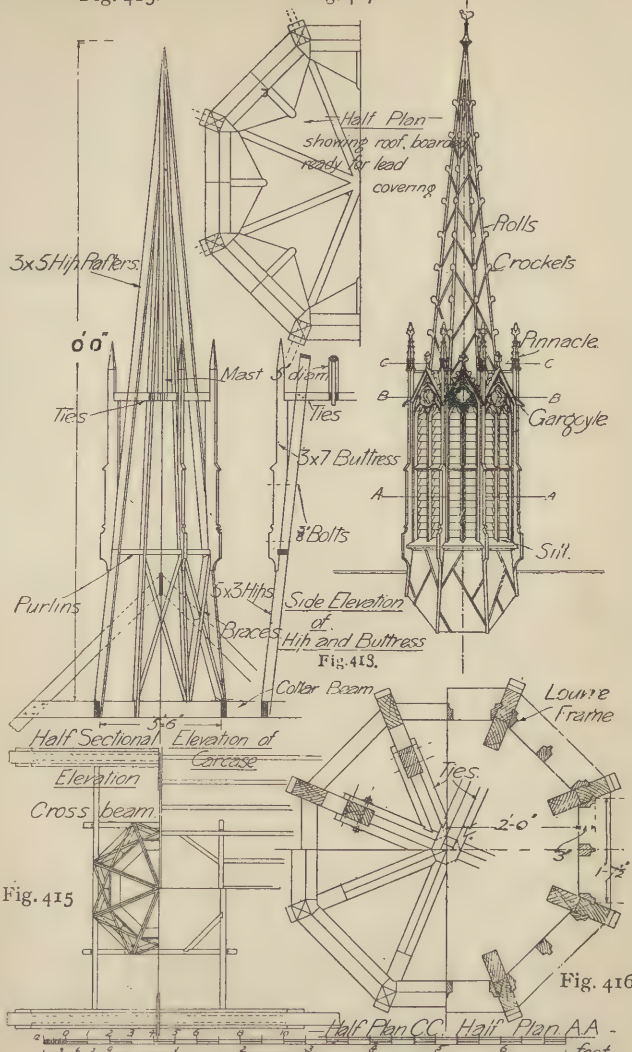


Fig. 418.

Fig. 415

Fig. 416

Flèche for Ventilating.—Figures 413 to 418 show a flèche for ventilating purposes such as would be in conformity with the mediæval roofs previously described. These flèches may be in plan hexagonal or octagonal. Being subject to considerable wind pressure, it is necessary to frame them well down into the roof. Figures 413 and 415 show an example fixed down to the collar beams of a roof. The flèche is placed centrally between two trusses, the collars of the latter being connected by two cross beams, and these again have two transverse members framed into them, forming a square that encloses the timbers placed at an angle of 45° which form the octagonal base of the flèche. The faces of the octagonal pyramid are inclined at an angle which varies between 80° and 85°. The hips are birdsmouthed into the angles of the octagonal base, and at their upper ends are nailed to a central mast. A series of purlins are placed at the sill level; and to form a base for the mast a series of ties, constructed as shown in figure 418, are fixed to the hips, the masts being joggled into this series of ties. The part of the structure below the sill is braced, as shown in figures 413 and 415. The buttresses are framed and bolted to the hips, the louvre frames are constructed as shown in figure 416, tongued into the buttresses, the whole of the sills being housed into the latter. The upper portion of the flèche is then boarded, the gables and the rolls being formed as shown in figure 414, it is then covered in with milled lead. The lead covering extends over the crowning moulding of the gable. The pinnacles are of cast lead fixed over the wood cores forming buttresses. The crockets on rolls and gables are of cast lead. The sheet lead covering is usually laid to the herring-bone pattern as shown, and welted at joints. The louvres below are formed of stout copper or zinc turned up at its back edge. The rain-water from the roof is drained away through a lead pipe forming a gargoyle, the lead pipe

passing through the buttress, as shown in figures 414 and 417.

Curved Rib Trusses.—The maximum interior height of buildings has been attained by using curved rib trusses. These may be made in timber in two ways: (*a*) built-up curved vertical plates; (*b*) built-up ribs with thin plates bent to the contour of the curve. In the latter case the plates are bonded as shown in the built-up method, figure 546, *Elementary Course*, and fixed the requisite distances apart by struts.

Steel Roof Trusses.—The types and details of iron and steel roof construction have been given in my *Elementary Course.* The method of determining the magnitude of the stresses on the members has been given in the chapter on Graphic Statics. The joint fastenings will now be considered.

Calculation of Joints.—These may be resolved under two heads: (1) Those which are riveted together, and theoretically are not considered to allow of free movement, and also where the latter must obtain where the truss is not properly triangulated; (2) Those in which every bar may be considered separate and free to rotate about a pin at its extremities.

All members in trusses calculated for stresses obtained by the method of Graphic Statics must theoretically be free to rotate, so that at any alteration of stress all the bars of the truss may be free to adjust themselves to offer the least possible resistance necessary to equilibrate the variation of pressure. The typical joint to satisfy this condition is the fork and eye joint, which should be the principle upon which all joints should be calculated and designed.

In small roofs, the rotation about the axis or pin is so slight that it is often neglected, and the joints are often riveted together, the parts being equated and calculated, as shown in the article on Riveting.

Any part of a joint must be equally strong to resist the maximum stress it is possible to be subjected to. The area of the members joined usually being given, the eye or fork must not rupture before the member of which it is a part would fail under its length stress.

The strength of the members joined must be determined or known, then there will be four parts of the joint to calculate and equate.

a Area of the pin; this is determined by its shearing strength.
b Thickness of eye; this is determined by its bearing strength.
c Width of jaw cheeks, as *a—b*, *c—d*, figure 420, and is determined by its tensile strength.
d Shearing area of jaws, as *e—f*, *g—h*, figure 420, and is determined by its shearing strength.

Let S = Value of resistance of members joined, or the maximum stress that the part is subjected to.
f_t = Tenacity of joint material.
f_c = Resistance to crushing or bearing.
f_s = Resistance to shearing stress.
a = Sectional area.

Let f_t, f_c, and f_s for mild steel have values of 6, 6, and 5 tons safe load per square inch respectively.

The sum of the two thicknesses of the fork, $kl + mn$, is made equal to the thickness of the eye (t), as shown in figure 419.

An example will be worked to illustrate the above.

Examples: Calculate the dimensions of the fork and eye joint for tie rods of $1\frac{1}{2}$ inches diameter:—

$$S = 1{\cdot}5^2 \times {\cdot}7854 \times 6 = 10{\cdot}603 \text{ tons.}$$

The strength of the four parts must be equated to this value.

(*a*) The pin might fail by shearing across two sections, then—

$$S = 2\,af_s$$

but allowing for pin not fitting tightly, the working shearing

resistance should be taken at not more than $\frac{3}{4}$ of the value given for f_s, therefore

$$S = \tfrac{3}{4} \times 2 \times a \times f_s$$

$$\therefore S = \tfrac{3}{4} \times 2 \times d^2 \times \cdot 7854 \times 5$$

$$\therefore d^2 = \frac{10 \cdot 603}{\frac{3}{4} \times 2 \times \cdot 7854 \times 5}$$

$$\therefore d^2 = 1 \cdot 800, \text{ and } d = 1 \cdot 341 \text{ nearly.}$$

Let the diameter of the eye be taken as $1\frac{1}{2}$ inches.

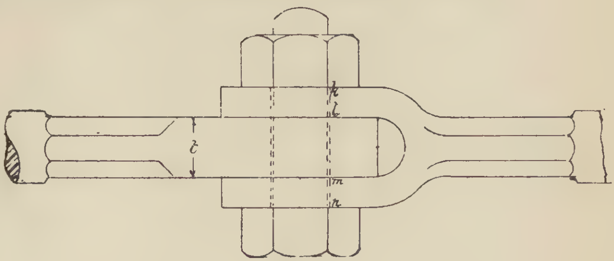


Fig. 419.

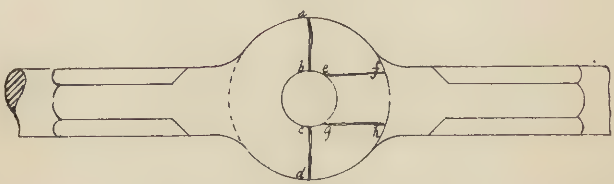


Fig. 420.

(*b*) The joint might fail through the bearing area for pin being insufficient—

$$= bc \times t \times fc \therefore t = \frac{S}{bc \times fc} = \frac{10 \cdot 603}{1 \cdot 5 \times 6} = \frac{10 \cdot 603}{9} = 1 \cdot 18 \text{ ins. nearly.}$$

(*c*) The joint might fail by tearing across the cheeks. Let $a—b = c—d = B$, then—

$$S = 2B \times t \times f_t \therefore B = \frac{S}{2\,tf_t} = \frac{10 \cdot 603}{2 \times 1 \cdot 18 \times 6} = \cdot 75 \text{ inches nearly.}$$

(*d*) The joint might fail by the eye shearing in front

across two sections, *ef* and *gh*, figure 420; then let $ef = gh = L$, then—

$$S = 2\,L\,tf_s \therefore L = \frac{S}{2\,tf_s} = \frac{10{\cdot}603}{2 \times 1{\cdot}18 \times {\cdot}5} = {\cdot}90 \text{ inches nearly.}$$

Practical Sizes.—(*a*) and (*b*) might be made $1\frac{1}{2}$ inch diameter and $1\frac{1}{4}$ inch respectively. It is usual to add 50 per cent. upon the values of *c* and *d*, as the stresses are not equally distributed over the resisting area. The value of (*c*) = ·75 + ·375 = 1·125 = $1\frac{1}{8}$ inches; the value of (*d*) = ·90 + ·45 = 1·35 inches.

Steel Arch Rib Truss Calculations.—The sections for the members of the steel arched rib truss shown in figures 780–787, *Elementary Course*, may be computed as follows, typical compressional and tensional sections and riveted joints being taken:—

Draw the stress diagram as shown in figures 337 and 338, and measure the stresses on the members. The following table gives the values taken from that diagram:—

Bar.	Stress in lbs.	Nature.	Bar.	Stress.	Nature.
P—30	28100	+	Q—11	8100	—
31—30	—	—	31—11	42500	+
30—29	20200	—	12—11	8500	+
1—29	13100	+	10—12	5700	—
29—28	67500	+	13—12	19500	+
28—31	58800	—	13—31	19200	+
28—27	30200	—	13—14	7800	—
2—27	65700	+	9—14	7300	+
27—26	32400	+	14—15	37200	+
26—31	86500	—	15—31	17000	—
26—25	4000	—	15—16	9800	—
3—25	92800	+	16—8	38600	+
25—24	37700	—	17—16	5900	+
24—31	54500	—	17—31	21700	—
24—23	20600	+	17—18	1200	+
4—23	54200	+	7—18	40800	+
23—22	34100	—	18—19	8000	—
22—31	30000	—	19—31	19600	—
22—21	28200	+	19—20	8200	+
5—21	29500	+	6—20	32000	+
21—20	37000	—			

Compressional.—Taking as a typical member bar 3—25 proceed as follows: Measure the stress and the length, then consult merchants' tables, such as Carnegie Co., Dorman Long, Redpath Brown & Co., &c., or preferably the British Standard Sections, and select a suitable section; determine or obtain the radius of gyration, then use the tables in this book for the values of compression (p) and the sliding scale of the factors of safety, and determine the area required. If the area of the proposed section is sufficient without undue extravagance, it would be selected; if not, another section would be taken and computed thus: bar 3—25 is in compression 92,800 lbs. and measures 6 feet 3 inches. From Carnegie's list two 4 inch × 4 inch × $\frac{3}{8}$ angles back to back gives a radius of gyration of 1·86.

$\therefore \frac{l}{r} = \frac{75}{1\cdot86} = 40$ nearly, $\therefore$ from tables given for p and safety allowable stress $= \frac{57692}{4\cdot7} = 12270 \; \therefore \; \frac{92800}{12270} = 7\cdot56$ inches area required.

4 × 4 × $\frac{3}{8}$ angles would not give enough area, but 4 × 4 × $\frac{1}{2}$ would be sufficiently near.

Tension — Bar 26 — 31 is in tension and stressed to 86,500 lbs. The safe allowable stress per square inch is 60,000 ÷ 4 = 15,000 lbs.

$$\therefore \; \frac{86500}{15000} = 5\cdot76 \text{ net area required.}$$

Two 4 ft. × 4 in. × $\frac{1}{2}$ in. steel angles will therefore be ample after deducting the loss of the two $\frac{3}{4}$ × $\frac{1}{2}$ rivet holes.

Number of Rivets.—Take the riveting of a typical bar 25—24, it is stressed 37,500 lbs., therefore there must be a number of rivets sufficient to resist shearing stress and to give enough bearing area.

From the table given on page 394, the value of a $\frac{3}{4}$ rivet in single shear is 4,946 lbs.; these would be in double shear; therefore each rivet has a shearing resistance of 9,892 lbs. The value of the bearing area resistance from

the same given table is 5,630 lbs.; therefore, the bearing area determines the number of rivets.

$$\therefore \frac{37500}{5630} = 7 \text{ nearly.}$$

Steel Mansard Truss.—The computation for the section of the principal and gusset plates of the Mansard truss shown in figures 788 to 793, *Elementary Course*, may be made as follows:—

From the frame and stress diagrams figures 339 and 340.

The trusses are 15 feet apart, the lengths of the members do not exceed 12 feet, the dead load is to be taken as 50 lbs. per foot super, and the normal wind pressure as $50 \times \cdot 987$ in lbs. per foot super.

The normal wind pressure on lower principal $= 12 \times 15 \times 50 \times \cdot 987 = 8{,}883$ lbs.

The dead load on lower principal $= 12 \times 15 \times 50 = 9000$ lbs.; this resolved normally to slope $= 3600$ lbs. about.

The section of the principal must be such that it can resist as a beam under bending stress the normal pressure of the wind, dead load, reaction of gusset plates + the direct stress due to being a member in a frame.

$$\begin{array}{ccccccc}
\text{Moment of wind pressure} & + & \text{Moment of dead load} & + & \text{Moment of gusset's reaction} & = & \text{Moment of resistance.} \\
\frac{W_1 l}{12} & + & \frac{W_2 l}{12} & + & \frac{W_3 l}{8} & = & f\frac{I}{\delta} \\
\frac{8883 \times 144}{12} & + & \frac{3600 \times 144}{12} & + & \frac{14200 \times 144}{8} & = & f\frac{I}{\delta} \\
106596 & + & 43200 & + & 227200 & = & f\frac{I}{\delta}
\end{array}$$

$$\frac{I}{\delta} = \frac{373996}{15000} = 24 \cdot 93$$

From Redpath Brown & Co.'s list two 8 in. $\times$ $3\frac{1}{2}$ in. channels, 52 lbs. per foot run, 15·2 square inches area, give each $I = 63 \cdot 5$ and $\delta = 4 \therefore \frac{I}{\delta} = \frac{63 \cdot 5 \times 2}{4} = 31 \cdot 75$.

This will allow sufficient for the small extra area required for the direct stress.

Gusset Plates.—These are shown of $\frac{1}{2}$ inch steel plate and must have a minimum sectional area of $\frac{18500}{15000} = 1{\cdot}23$ square inches.

Number of Rivets for Gusset Plates.—The gusset plates are as measured from the diagram stressed 18500 lbs., the rivets are in double shear, therefore as may be seen as before from the Table, the number required on each side of joint will be determined by the bearing area.

$$\therefore \frac{18500}{5630} = 4 \text{ nearly.}$$

ROOF COVERINGS.

The covering placed on a roof often determines the pitch, there being a minimum angle at which roofs covered in any material must be pitched in order to dispose of the rain-water, and to form watertight joints. A table giving the minimum pitch for the chief materials used is given in my *Elementary Course*. The pitch of a roof is often determined by the material which is most easily obtainable in the locality, and also by climatic conditions as stated in the *Elementary Course*.

The coverings of roofs are of the following kinds: metallic, stone, earthenware, thatch and glass. Thatch is now obsolete for all but cottages in rural districts and farm buildings.

The following, which are the materials chiefly used, will be described, viz.: Lead, zinc, copper, corrugated iron, slates, tiles, slabs of stone, asphalte, asphalted felt, thatch, glass.

Lead.—Lead is obtained from the ore which is found in Nature as lead sulphide, termed galena (PbS), by smelting the latter in a reverberatory furnace. The metal is cast into pigs, and from them is manufactured for roofing

purposes into sheet lead, being obtainable either as cast or milled sheets. The metal is malleable and ductile, and the ease with which it may be worked into any of the forms required makes it valuable for roofing purposes. The uses to which lead is put in roofs is fully treated in the article on Plumbing, in my *Elementary Course.*

Zinc.—Zinc is obtained from zinc ore, which is found in the form of zinc carbonate ($ZnCO_3$), or as zinc sulphide (ZnS). It is reduced to the metallic zinc by a process of roasting and subsequent distillation with carbon.

Zinc is a bluish-grey metal. When exposed to moist air the surface rapidly becomes oxidised, but this film of oxide protects the remainder of the metal from any further corrosion. This property makes it valuable for roofing, for which purpose it is used in two forms: first, as sheet zinc; secondly, as a covering to sheet iron, which when so covered is said to be galvanized.

Zinc is readily soluble in dilute acids, therefore it will last longer in pure country air than in large towns, or near the sea. Lime, soot, oak, woods containing acids, and the urine of cats readily decompose zinc. Zinc must not be fixed in contact with other metals except with iron, as a galvanized coating or a galvanic action will set up on the addition of moisture, which will decompose the zinc. Zinc expands and contracts to a large extent; it must therefore be fixed in such a manner as to allow this action to take place freely. Zinc readily burns.

Zinc is now largely used in place of lead, being much cheaper and lighter. Roofs are covered with zinc in a similar manner to lead, in sheets about 7 feet × 2 feet 8 inches to 8 feet × 3 feet, with wood rolls trapezoidal in section, being $1\frac{3}{4}$ inch in height, $1\frac{1}{2}$ inch at bottom, and $1\frac{1}{4}$ inch at top. The sharp angles are taken off with a plane. Zinc cannot be bossed at the angles like lead, but has to be cut

and soldered as shown in figures 421 and 422. Messrs. Braby & Co. have patented a method of folding the ends of the sheets and rolls to do away with the necessity of soldering.

The ordinary method of laying a zinc flat is as follows :— The wood flat is prepared in a similar manner to those for lead, having drips arranged at intervals of 6 feet 6 inches apart, and a fall in that length of 1½ inch. The whole surface should then be covered with asphalted felt. If this be omitted the zinc is liable to be cut by the sharp edges

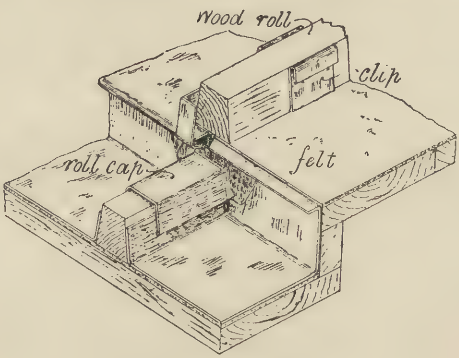


Fig. 421.

or irregularities of the boarding when the latter casts. The rolls are now nailed to the boarding, three clips 2 inches wide and 6 inches in length are fixed beneath each roll, and turned up sharp against the side of the roll. The sheets are then placed in position between the rolls, having previously had the edges turned up for about 1⅝ inch on two sides, and for the amount of the drip, plus ½ inch on a third edge, the extra ½ inch being also turned at right angles to the turned-up edge, the angles being cut and made good by soldering. The lowest edge is turned down and formed as a small hollow roll, which clips the sheet or gutter below it. A small gusset piece has to be soldered on to connect the

turned-up edge to the turned-down edge at the two angles. When two adjacent sheets are laid, the clips are turned down, to secure them, and leaving them free to expand or contract. The roll cap is now prepared, being bent to fit over the roll, and extends to within about ½ inch of the bottom of the latter. The free edges of the roll cap are bent slightly inwards. A flat piece of zinc, the edge of which is cut to the shape of the roll cap, is soldered at right angles to it at its highest end, thus forming a flat turned-up surface that fits against the vertical face of the

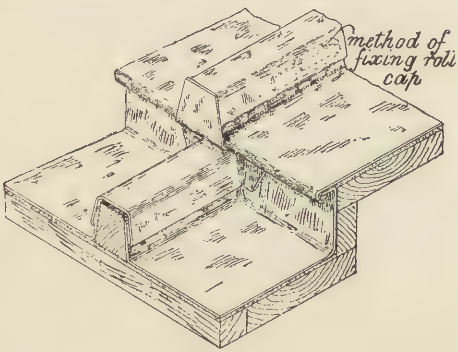


Fig. 422.

drip. At the lower end of the roll cap a flat piece of zinc is soldered on to cover the end of wood roll, as shown in figures 421 and 422. The bottom edge of the latter piece extends below, and is folded under the edges of the two adjacent sheets. To secure the roll caps, strips of zinc about 3 inches in length, and about ½ inch in width, are soldered at one end to the inside of the sides of the roll cap, the free ends of the strips pointing towards the highest end of the roll cap. The strips are fixed in pairs on the cap, so that when the latter is in position, the unsoldered part of the strips are coincident with the turned-down ends of the clips fixed under the roll. In fixing the cap, the latter

is placed on the roll a few inches from its proper position. It is then pushed home, the above-mentioned strips pass under the clips and thus secure the cap. An inferior method of securing the cap is to nail it with galvanized nails, and enveloping the top of the nail with solder; this does not allow the cap to expand and contract in the direction of its length. The arrangement of the sheets against wall, the flashings, soakers, etc., are similar to the same details in lead work, with the exception that at all free edges, such as the free edges of flashings, a small bead should be formed to stiffen the edges, by working the edge about a wood rod three-eighths of an inch in diameter, the free edge being fixed towards the wall.

Copper.—This metal is obtained from ores of varied combinations, from which it is extracted by roasting, calcining, and melting with certain fluxes.

It has been used largely for roofing purposes, but owing to its expense it has been superseded by zinc and lead; it is ductile and very tenacious. Owing to the latter property it is valuable as a covering for roofs of steep pitches, domes, and vertical surfaces, where it can be used. Comparing it to lead, as used it is in much thinner and lighter sheets, and in similar positions, owing to its relatively great tenacity, it resists better the crawling action so detrimental to lead, due to the expansion of the metal.

Copper is durable in temperate climates; when exposed to the atmosphere it becomes covered with a film of copper carbonate, turning to a green colour, which is often highly valued; this film protects the metal from any further action of the atmosphere. In hot climates the metal corrodes quickly; in the presence of great heat and moisture the metal is oxidised; the heat also causes the metal to buckle. Copper is more durable than zinc. The method of laying copper for roofing is similar to zinc.

Copper is very malleable, and can be hammered to ornamental designs.

Corrugated Iron.—Corrugated iron consists of thin sheets of iron that have been passed through rollers, and bent into a number of waves or corrugations, the distance from centre to centre varying from 3 inches to 5 inches (as shown in figure 734, *Elementary Course).* This has the effect of endowing the sheets with a great addition of strength, and, together with its lightness, renders it capable of covering large surfaces with very few supports.

Corrugated iron is made in sheets about 6 feet in length, by about 2 feet 6 inches in width. The corrugations are fixed parallel to the slope, the sheets being screwed with galvanized screws to purlins, ridge pieces, and plates fixed at intervals of about 2 feet 9 inches apart on the slope, the total number of horizontal members for fixing to, being two for each sheet, plus one.

The galvanized iron screws are driven through holes punched through the highest sloping line of the curves, where the iron has the minimum degree of exposure. Each sheet overlaps the one below it from 6 inches upwards, according to the pitch, and also the sheet beside it by one corrugation. Special pieces are manufactured for covering hips, ridges, and valleys. Owing to the rapidity and ease with which corrugated iron may be fixed and taken down it is largely used for temporary buildings.

Corrugated iron is usually galvanized to prevent oxidation, which is accomplished as follows:—The iron is carefully cleaned, then heated and immersed first in zinc chloride, which forms the flux, and secondly into molten zinc; a thin film of zinc adheres to the iron. Care should be taken that the zinc covering is not damaged, and that at all places where the sheets are cut they are painted, otherwise on the addition of moisture a galvanic action will

set up between the metals, destroying the affected part and rendering the sheet defective.

Corrugated iron is largely used in the colonies, and in districts where water is scarce, to collect the rain water, which is conveyed from the roof to the reservoir, cleaner than from any other covering. A similar section to the corrugated iron is now made of glass for the admission of light in buildings roofed with the former material.

Slates.—Slates are described in the chapter on Stones, and the methods of fixing are fully treated in the *Elementary Course.*

Tiles.—Tiles are fully described in the chapter on Bricks. The method of laying the plain tiles, with respect to the lap gauge and margin, is similar to slates, the margin and gauge allowed being usually 4 inches, and the lap $2\frac{1}{2}$ inches, disregarding the nail holes; they are laid on laths or battens, and are kept from sliding by oak pins or projecting nibs, and sometimes by nails. The ground to receive the tiles may be prepared in a similar manner to that for slates, as described in the chapter on Slating, *Elementary Course.*

Asphalte.—Asphalte is described in the chapter on Concrete. It forms a very good covering for flat roofs of concrete or timber, the methods of application being as follows:—In the former the concrete is worked to the necessary falls and carefully screened; the asphalte is then applied hot, as fully described in the article on Asphalte. In timber roofs the joists are fixed and prepared as for a lead flat, with the exception that no drips are required; on the top of these $1\frac{1}{4}$ in. × $\frac{3}{4}$ in. laths are nailed, with a space of $\frac{3}{8}$ inch between; over these is spread a layer of fine lime and hair concrete 1 inch in thickness; the concrete passes between the laths and obtains a key; over this is laid the asphalte $\frac{3}{4}$ in. in thickness. The gutters, which are simply

segmental grooves situated at the sides of the roof, are formed by cutting a small piece out of the top of the joists where they occur, and lathing and concreting over them, the finished gutter being formed in the asphalte.

About the parapet walls at the sides of the roof an asphalte skirting is formed, the top edge being tucked into the joint of the brickwork, which has been previously raked out to receive it, as shown in figure 423. This covering is

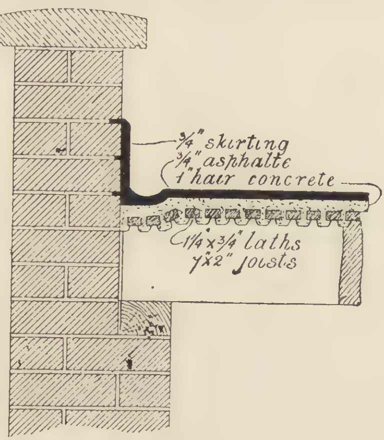


Fig. 423.

light and effective, one great advantage being that there are no joints for the water to soak through.

Asphalted Felt. — This consists of felt saturated with bitumen or asphalte; it is rarely used as a roof covering by itself, except on temporary buildings, but is largely used under other materials, such as beneath zinc, to protect it from being cut or corroded by the nails or sap in the boarding; or beneath slated or tiled surfaces, where, by its property of being a bad conductor, it preserves a more equable temperature in the interior of a building, and also

forms an extra protection against dampness should the outside covering become defective.

Thin Slabs of Stone.—These are employed for effect, or in districts where a thinly stratified stone is abundant, and where slates or tiles are scarce or expensive; they are mostly used in irregular shaped pieces, being at the best but roughly squared. They are fixed on battens in a manner similar to slates, and are described in the *Elementary Course;* they form an efficient but a heavy covering, and for their support require large timbers.

Thatch.—Thatch consists of bundles of wheaten straw laid with the length of the straw. The rafters are fixed as in ordinary roofs; battens about 2 in. × 1 in. are then nailed about 9 inches apart on to the rafters, and the straw, in small bundles, is then tied down to the battens. The thickness of the thatch varies from 9 inches to 1 foot. The pitch of the roof requires to be at least 45° to throw the rain off effectively. Thatch is a bad conductor of heat; the buildings are, therefore, warm in winter and cool in summer. It is sometimes used and presents, in rural districts, a picturesque appearance. Thatch is not sanitary, forms a harbourage for vermin, and is liable to decay and to destruction by fire.

Covering of Roofs with Glass.—In order to cover roofs with glass successfully the covering should be secured in such manner to permit the expansion and contraction of the glass, and yet to remain watertight, provision to carry away condensed moisture, to exclude the minimum quantity of light, and to reduce the cost of maintenance and repairs, which in most instances, where glass coverings are used on a large scale and fixed with putty, amounts to a considerable item. The following patent methods have been and are extensively used:—

(1) Rendle's "Invincible" system, as shown in figures

424 and 425, formed of two sections of rolled zinc or copper, between which the glass is secured by means of nuts and screws. For spans above 4 feet the section would be secured to small steel tees or moulded wood bars.

(2) "Braby's" system consists of two zinc or copper sections supported on moulded wood bars. The glass is laid upon an oiled cord supported by the lower section, and is secured by the upper section, which is screwed down to the wood, as shown in figure 426.

(3) Grover's "Simplex lead glazing" consists of lead sections, as shown in figures 427 and 428, either rolled about a steel tee or resting upon a wood bar. The glass is laid upon the lead bed and the edges of the lead section turned over upon the glass. Figure 428 shows one edge of the lead section ready to be turned down.

(4) "The British Challenge Glazing Co." This arrangement consists in clothing a steel tee bar with a lead section, as shown in figure 429, or covering a wood-moulded bar, as shown in figure 430. The details of the finishings at the lower rail or curb and at the head and side bar are shown in figures 431 to 433.

(5) Mellowe's "Eclipse" consists in a special tin lead cover section enclosing a steel tee or supported by steel or wood bars, as shown in figures 434 and 435.

(6) Helliwell's "Perfection" consists of a specially rolled steel bar supporting the glass, the latter being secured by a rolled zinc, copper, or lead cap. A strip of asbestos is placed between the cap and the glass, and the cap is fixed down with brass bolts and nuts, as shown in figure 436.

"*The Pennycook*" *Patent System of Roof Glazing* consists of mild steel bars termed astragals, rolled to a special section, with condensation channels, and fitted with double-folded heavy lead caps, which are secured to the web

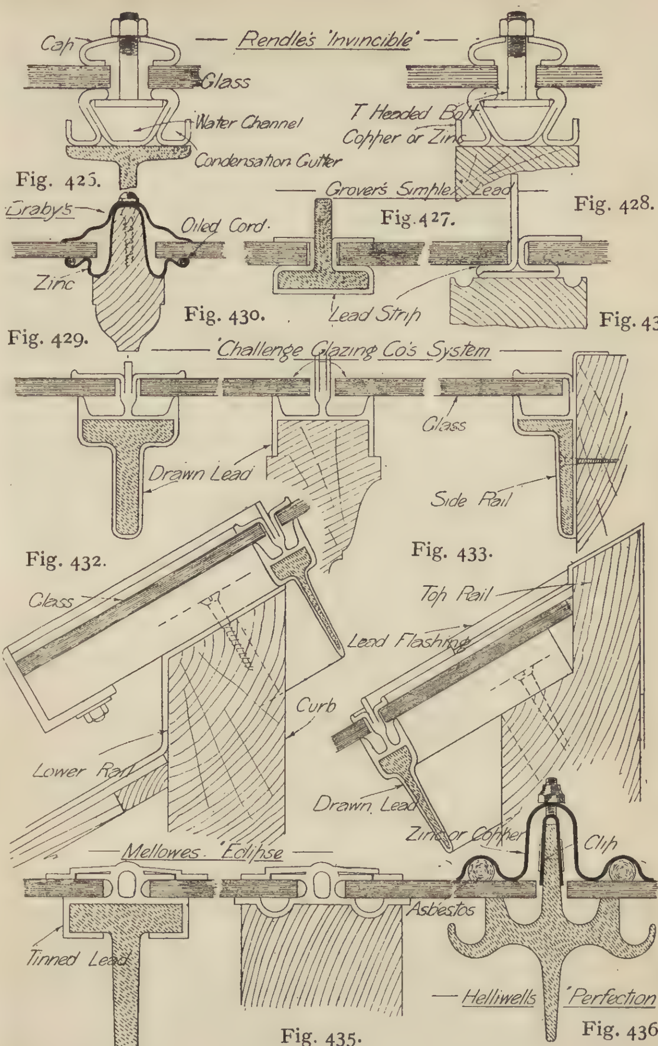


Fig. 424. Fig. 425. Fig. 426. Fig. 427. Fig. 428. Fig. 429. Fig. 430. Fig. 431. Fig. 432. Fig. 433. Fig. 434. Fig. 435. Fig. 436

of steel bars by solid lead rivets about 9 inches apart, as shown in figure 437.

A special feature of the lead cap is that it enfolds the glass on both the edge and outer face, thus giving it a better hold on the glass than a horizontal wing lying simply on the face of the glass.

The astragals leave the works with the lead caps already fitted to the steel bars, so that in glazing, all that has to be done, after pitching the bars to proper centres, according to the widths of the panes, is to lay in the glass on the table or flange of bars and turn down the lead wings of caps (which stand upright) and dress them down flat on glass with a wood tool.

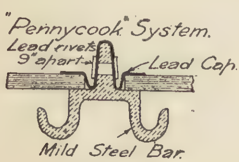


Fig. 437.

The width of the panes may be 24 inches for $\frac{1}{4}$ inch glass and any length up to 9 feet or more.

The astragals are made for spans up to 11 feet, and are joggled for lap of glass when in two panes deep on a long continuous bar, which does not need a flashing.

The steel bars are galvanized, and a combined shoe and stop is used for fixing to the bottom purlin. Any kind of glass may be used.

Roofs of all shapes can be glazed on this system, also domes and other spherical roofs.

Prices vary from $10\frac{1}{2}d.$ per foot (superficial) upwards, according to glass used and area to be glazed, etc.

Regulations.—The following regulations are stated by the Model Bye-Laws in regard to roofs :—

Every person who shall erect a new building shall cause the flat and roof of such building, and every turret, dormer, lantern-light, skylight, or other erection placed on the roof of such building, to be externally covered with slates, tiles, metal, or other incombustible materials, except as regards

any door, door-frame, window, or window-frame of any such turret, dormer, lantern-light, skylight, or other erection.

He shall also cause every gutter, shoot, or trough in connection with the roof of such building to be constructed of incombustible materials.

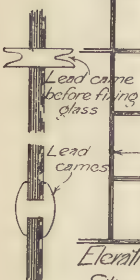
Every person who shall erect a new building shall cause the roof or flat of such building to be so constructed that all water falling on such roof or flat shall be received in suitable gutters, shoots, or troughs, and shall be discharged into a pipe provided.

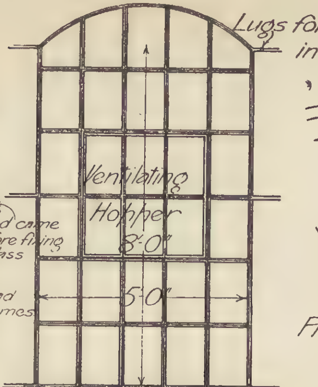
Metal Sashes and Frames.—Sashes for buildings of the factory and warehouse type are now usually made of wrought-iron or steel. Such sashes may be made of very large dimensions and of sections extremely light compared to those that would be required in wood. The frames are usually built in as the brickwork or stonework is carried up. They have lugs projecting from the boundary bars of the frame, as shown in figure 439, which are built into the carcase work. For ventilation, hoppers are provided, as shown in figure 441, which allow the sashes to revolve on their bottom edges; the method of fixing hopper, with the details, is shown in figure 440. The ventilating sashes may also be hung on centres similar to wood sashes. Details of the head and sill of the sash frame are shown in figure 442. Casement sashes and frames are also formed from gunmetal or steel; they are largely used, particularly in windows of the Gothic type, or in openings where stone forms the finishing both internally and externally. Their general lightness of construction and great strength compared with wood renders them valuable for window areas of small dimensions. Figure 445 shows a general view of a casement sash, and figures 443 and 444 the details through the head jamb and sill. These may be fixed with lugs as in

Fig. 439.

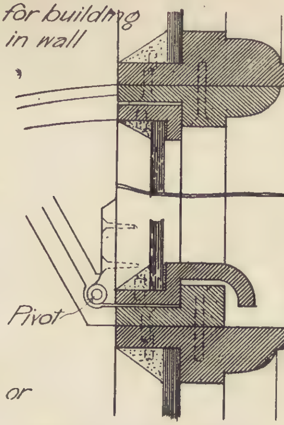
Fig. 440.

Fig. 438.



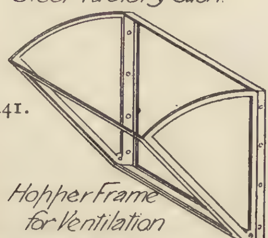


Elevation of Wrought Iron or Steel Factory Sash.



Vertical Section through Ventilation Hopper.

Fig. 441.



Hopper Frame for Ventilation

Fig. 442.

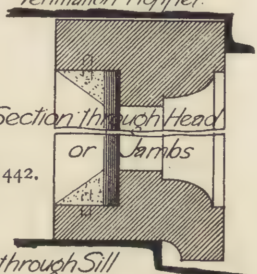


Fig. 443.

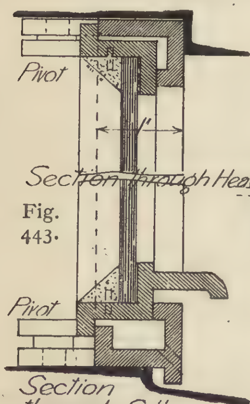


Fig. 444.

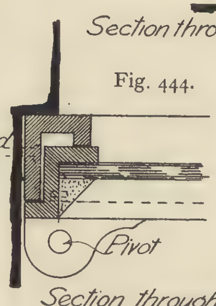
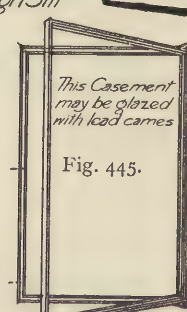


Fig. 445.



Elevation of Steel or Gunmetal Frame.

the previous example, or they may be fixed with screws as shown in figure 444. Figure 438 shows a section through a lead came, a method of glazing largely employed with metal sashes. At all the intersections the cames are fitted and soldered.

CHAPTER XIII.

JOINERY.

Continued from the Elementary Course.

Gothic framing.—The tracery in the Gothic styles is usually fret-cut and glued upon the panel with the grain in the same direction as the panel, as shown in figures 446 and 447.

The mouldings in framing of the Gothic styles are usually stuck on the solid. The mouldings are not jointed at the angles in the usual way, but are returned about the angles by what is known as a mason's mitre, as shown in figure 446. The framing is first fitted together; the mouldings are invariably stuck on the full length of the muntins, and the rails and styles are stopped where the muntins and rails respectively abut; the framing is then glued up, and held together by pins driven through the face of the frame, and passing through the tenon. The mitres are then carved at the angles. The upper horizontal edges of the members are often chamfered, not moulded (as shown in figure 446), the moulding on the vertical members either dying into the chamfer, or being stopped a few inches above the chamfered edge.

Figures 448 to 455 illustrate the application of Gothic framing to a bench end. Each bench, forming one of a series, usually has the framing tenoned into a horizontal plate extending the whole length of the system. The panel

is prepared with the tracery upon it, and is inserted between the styles, which are then connected at their upper ends by the top rail, which is mortised to receive the tenons on the styles. This is an exception to the ordinary method of framing in which the styles are mortised. Buttresses are

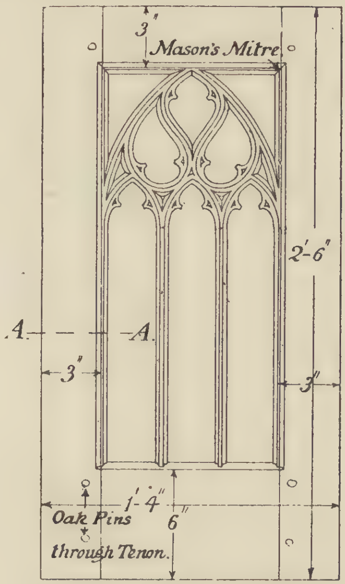
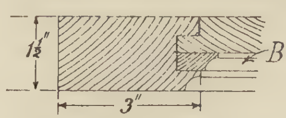


Fig. 446.

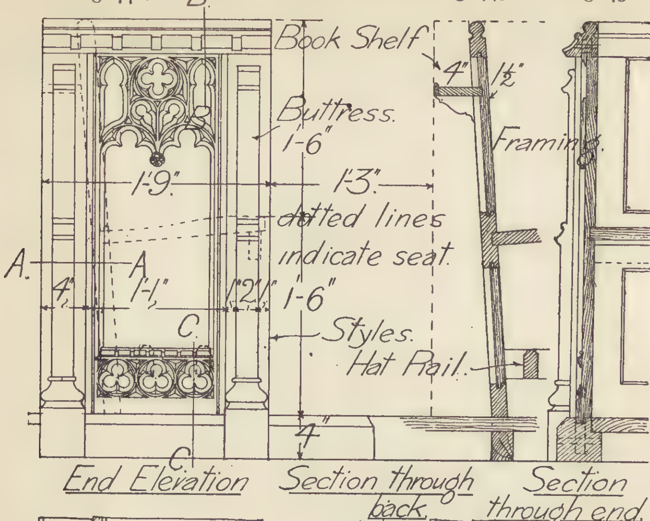


·:· Section ·A·A. ·:·

Fig. 447.

here placed on the outside of the styles, and although their function is chiefly decorative, they also serve to greatly stiffen the frame. Small joists about 2 inches in thickness are placed about 1 foot apart between the horizontal plates, and the floor boards are fixed. The seat backs consist of panelled frames, the panels usually being of V-jointed

Fig. 448. Fig. 449. Fig. 450.



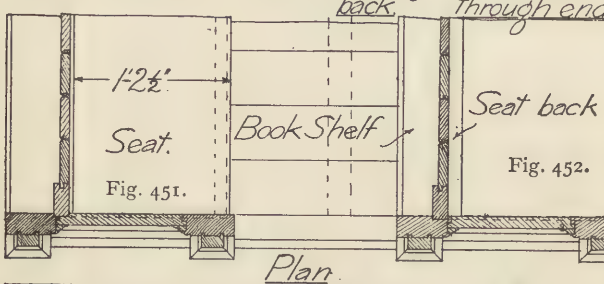


Fig. 451. Fig. 452.

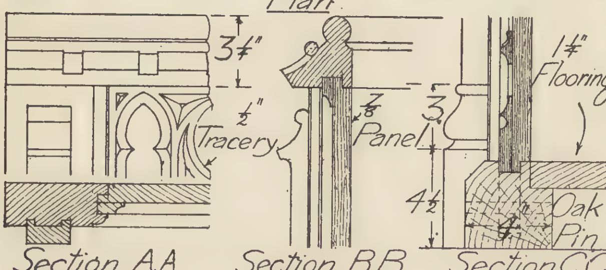


Fig. 453. Fig. 454. Fig. 455.

matching. They should be panelled to the ground to completely separate each pew from those adjoining, and the frame should slope about 1 inch in 1 foot for greater comfort. The seat should consist of one wide board, shaped on top as shown. The seat is housed into the back, and has a rail under front edge to support it, and if the seat is longer than 8 feet should have an upright under the centre. The seat and back are housed into the pew ends. Hat rails should be provided beneath the seat, as shown in figures 448 and 449.

Flooring.—Flooring may be classified as:—

(1) Batten.
(2) Block or Parquetry.

Floor boards are laid by one of the methods shown in *Elementary Course.* The floor boards in the best floors at the present time are generally laid with their lateral joints of the section, as shown in figures 613 and 614 of the above work.

It is imperative where the battens are out of hard wood, and are intended to be polished, that every precaution be taken to prevent the joints opening from shrinkage. This is accomplished by using narrow battens, thoroughly seasoned, and glueing the joints with a thin compound of glue and whiting.

Polished wood floors are usually laid upon a counter floor.

Counter Floors.—These consist of ordinary pine battens, usually with a square joint, laid diagonally upon the joists in order that none of the joints shall coincide with the joints in the floor above. The counter floor, when cleaned off, forms a perfectly plane surface upon which to fix the hard wood battens, the latter being wrought to one thickness.

Parquetry Floors. — Counter floors instead of being covered with battens are often overlaid with small blocks about 1 inch in thickness, laid to various patterns either dowelled or tongued together, and glued both to the counter floor, and to each other. Where the pattern lends itself to be so treated, the blocks are glued up in squares varying from 12 to 18 inches length of side before being fixed, for facility in laying.

The joints between the squares are grooved, tongued, and glued, the tongue being placed two-thirds of the thickness from the top, and fixed on two of its edges with a screw.

Where patterns similar to the above are used, a straight border is usually fixed about the room to be treated, wide enough to extend beyond all small projections in the skirting, such as the bases of pilasters, etc., in order to form a straight line against which the pattern may be finished. The border is returned about all large projections, chimney breasts, etc. The distances between the borders should be set out to avoid all irregular cutting of the patterns, multiples of the latter being preferable.

Plain Wood Blocks.—These are often laid to herring-bone and other patterns, and are fixed by bedding in a mastic cement, composed in the proportion of 1 cwt. pitch to $7\frac{1}{2}$ gallons of coal tar, boiled together for at least one hour, so that when cold it may be elastic or tough if laid on concrete; or a compound of glue and whiting if laid on a counter floor. The long bottom edges of the blocks have a dovetailed shaped groove taken out of them in order to key the block to the cement, and at the ends there is a small dovetailed shaped projection to key one block to the other.

Wood Finishings.—The wood finishings of a room often or partly correspond to the parts of an order in Roman Classic, the members of the latter including, plinth, die,

cornice of die, column or pilaster, architrave, frieze and cornice, whilst in the former the similar details are known

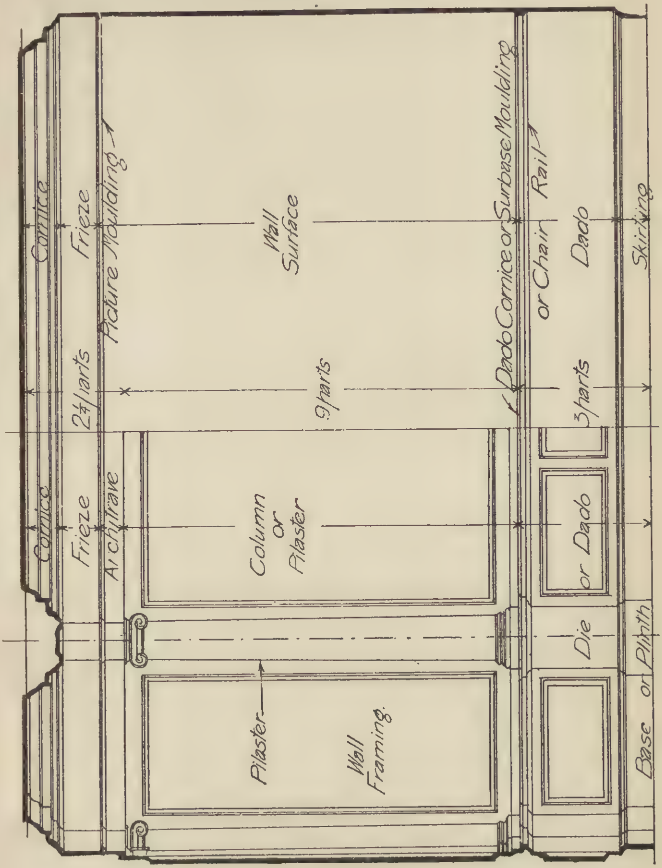


Fig. 456.

as skirtings, dado, surbase mouldings or chair rails, wall framing, architrave moulding or picture rail, frieze and cornice as shown in figure 456. The absence of wall

framing and columns or pilasters in rooms should not interfere with the proportions of the skirting, chair rail, picture rail, width of frieze or cornice.

Skirtings.—Skirtings in joinery consist of boards laid horizontally about the walls of rooms, etc., at their lowest part, primarily to protect the wall from damage; and, secondly, to form an ornamental base for a finish.

There are three kinds of skirting in common use. (1) A plain board, which may be square or moulded at its upper edge. This, where the walls are of plaster, is fixed to a horizontal ground fixed to plugs driven in the wall. The top edge of the ground, as shown in figure 457, is splayed to form a key for the plaster, and is placed about three-eighths of an inch below the top of skirting. Short, upright blocks are fixed between the skirting and floor about every 3 feet to form a backing. The heart side of the skirting-board should be used as the face, in order that the natural tendency of the board to cast would only cause its top edge to bind more tightly against the face of the plaster. The skirting may be tongued into the floor at its bottom edge, so that should any shrinkage occur there would not be an open joint at that part.

The skirting is only nailed along the top edge, so that it is free to shrink upwards without splitting along its centre. In inferior work the skirting is only scribed to the floor.

(2) The skirting, shown in figure 458, is known as double-faced or built up. These are constructed out of two pieces, first, in narrow skirtings to gain in effect by forming a sunk face, and secondly, in those of greater width to divide the shrinkage between two or among more pieces. The lower part of the skirting is tongued to the floor and fixed at its top edge; it has a groove in the latter to receive the second part, which is also fixed at its top edge.

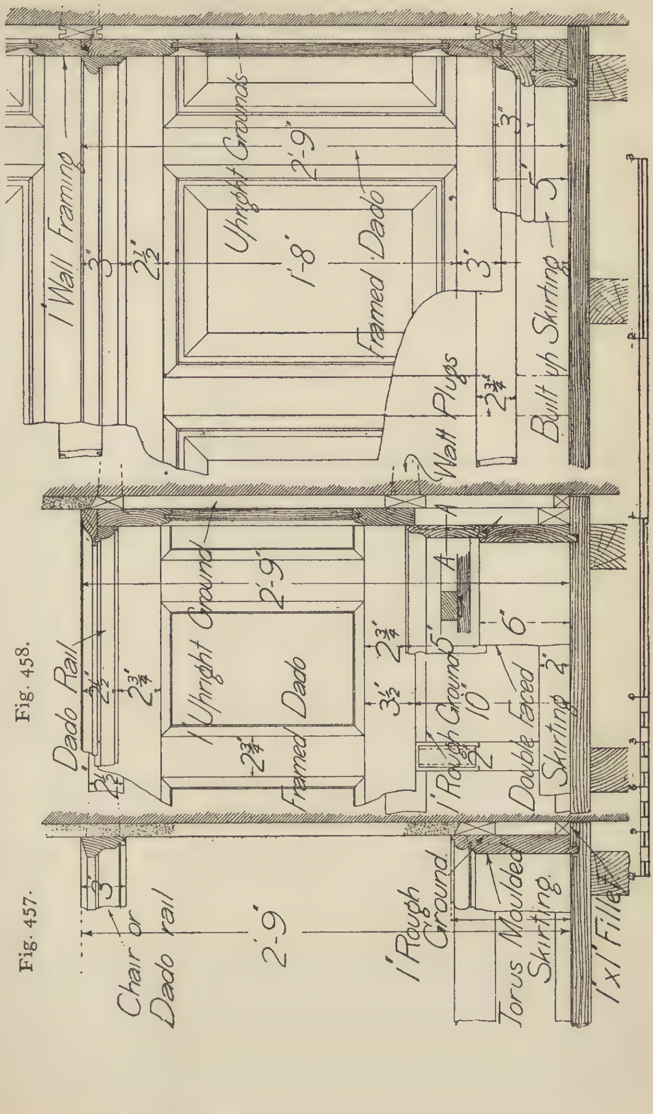


Fig. 459.

Fig. 458.

Fig. 457.

This skirting may be fixed to grounds on a wall to be plastered, as in the previous case, or it may be fixed to wood framing prepared, to form a backing, as shown in figure 458.

(3) The third class of skirting is shown in figure 459; it is employed where the material is hard wood, the projection great and the method of fixing is not desired to be visible.

The skirting is built up of a number of pieces glued together with their heart sides outward, in order that any tendency to twist in either would be counteracted by the other. If the skirting be out of hard wood of good figure, the back piece is usually made of pine or some less expensive wood. The skirting has a groove on its top edge to receive the framing. This solid block is then placed in position in the groove in floor, and screwed through the top edge to a rough wood ground, as shown in figure 459.

Skirtings are mitred at all external angles about projections; at all internal angles the plain vertical faces are grooved and tongued together, and all moulded surfaces are scribed or mitred to each other.

Dados.—Wood framings placed against the lower parts of walls between skirtings and chair rails, primarily for protection from injuries by blows from furniture or other means, and also to form an ornamental feature in the room, are known as dado framings.

There are two general kinds of wood dados: (1) Those formed of boards jointed and glued together, and laid horizontally; (2) framed and panelled, these latter admitting of a great variety of design.

Horizontal Dados.—These are usually formed of boards 1 inch in thickness with glued and tongued joints. The stuff is kept from casting by means either of dovetailed keys or battens secured with screws to the panels, the former being placed through slots in the batten to allow the stuff

to shrink and expand freely, or by a rebated batten secured to the stuff by means of hardwood buttons, to allow of lateral motion without casting. These three methods are shown in figures 876 to 879, *Elementary Course.* The keys or battens are placed not more than 3 feet apart, and at their lower ends extend to and rest upon the floor. The dado is fixed to the wall by nails or screws along the top edge, the latter being inserted, one through every key or batten and into a wood plug, which has been previously driven into the wall. The top edge is finished by having a cap mould fixed along the top edge. The battens along the lower edge are packed out with blocks, flush with the face of the dado to form a backing for the skirting, to which the latter is fixed, as previously described.

Framed Dados.—These are panelled frames made from 2 feet 9 inches to 7 feet in height. The panelling, which may be arranged to any design, usually has a skirting at the base; in this case the dado runs to the ground, and has the skirting fixed on the face. The lowest rail of dado that is seen projects about 1 inch below the top of the skirting; the dado also has a narrow rail about 2 inches in width at its lowest extremity, which is connected to the seen bottom rail by muntins, as shown in figure 458. These act as backings to the skirtings, and should not be more than 3 feet apart. The narrow rail is scribed to the ground, to which it is fixed by nails driven through it into the floor boards. The framing is fixed to rough wood grounds that have been previously fixed to the wall. A rough ground should be fixed behind every continuous horizontal member, and an upright muntin, should the latter not occur closer, at least every 3 feet apart, these being spaced to come behind the muntins.

Where built-up skirtings are used, the dado is dropped into a groove, as shown in figure 459. If the dados are painted, they may be fixed by driving nails

through the face of the muntins into the backings; but for polished work the fixing is obtained by screwing to rough grounds as shown in figure 459; but where very high dados are fixed, they must either be made of thicker stuff and secured, as shown in figure 459, or else screws driven through the face and pieces let in, the grain being carefully matched.

The capping is usually fixed, as shown in figure 458, a moulding being glued on to the top rail of dado before the latter is fixed, and over this a thin capping is placed, being scribed to the irregularities of the wall and glued to the dado.

Wall Framing.—Walls of rooms are often entirely covered with wood framing, secured to wood grounds in the manner described for dados. The lowest edge of the frame fits into a groove in the dado rail, as shown in figure 459. Its upper edge is either tongued to the bottom member of the cornice, or, where a frieze is arranged, to a small moulding which acts as a picture rail.

Picture Rails.—These are small moulded rails fixed about 1 foot or 1 foot 6 inches below the cornice, having a groove on their upper surface in which brass hooks, from which pictures may be hung, are fitted. Figure 465 shows one fixed to the plaster wall.

Frieze.—It is not necessary to frame wood friezes, these being fitted as panels, being grooved along their bottom edge to the picture rail, and at their upper edge to the bottom member of the cornice; they have upright wood backings fixed behind them about 3 feet apart. Friezes exceeding 9 inches in width should be keyed to prevent casting. The friezes are often highly carved and painted. Where this is done, allowance must be made for the part hidden by the projection of the picture-mould or architrave, and all rails of frames and margins, where placed at a height above the eye, must be made slightly wider than

corresponding rails at the height of the eye δ, or vertical members, to compensate for the apparent loss in width, owing to the angle at which they are seen.

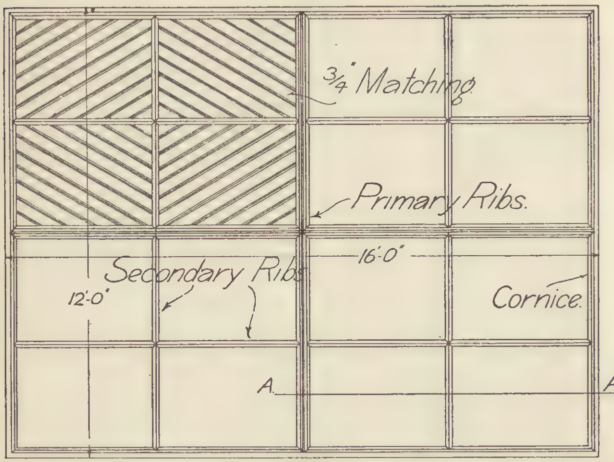
Cornices.—Wood cornices should always be built up from small sections tongued together and fixed at the pitch of the cornice, as shown in figure 464. Where the cornice is fixed about circular plans they should be prepared from rectangular sections as shown in figure 464. The heading joints should not be made across the whole section; but the pieces should be bonded together, each joint being butted, tongued or dowelled, and glued. The cornice may be made any length without loss of strength. Secondly, the mitres may be made more easily and better in small pieces than they can in wide pieces. When all the pieces have been fitted, they are glued and blocked together, raised to their place in long lengths, and fixed to grounds, as shown in figure 464. It is a very customary practice in interiors to extend the projection of the classic cornices, as they are seen chiefly from positions more directly underneath.

Ceilings.—Ceilings are often covered in wood framing, and may be done in three ways: First, by ordinary wood frame panelling fixed to the underside of the joists; secondly, ceilings are often covered with matchboarding with moulded ribs fixed to the face, presenting a panelled appearance; thirdly, coffered ceilings are constructed. In these, the upper members of the cornice are continued across the ceiling, and by the intersection of the pieces form a number of deep panels termed coffers, as shown in figure 462.

The first method is the simplest. In this, a piece of panelled framing, usually moulded, and formed to the shape of the ceiling, is screwed to the underside of the joists. The framing is usually prepared and fitted together on the ground. It is then taken apart, raised in convenient sized pieces, and fixed.

The second method, as shown in figure 460, is largely adopted in the late Gothic styles, the ceilings of many

Fig. 460.



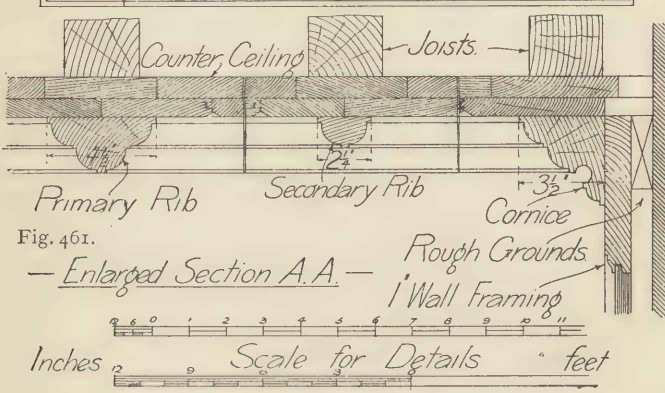
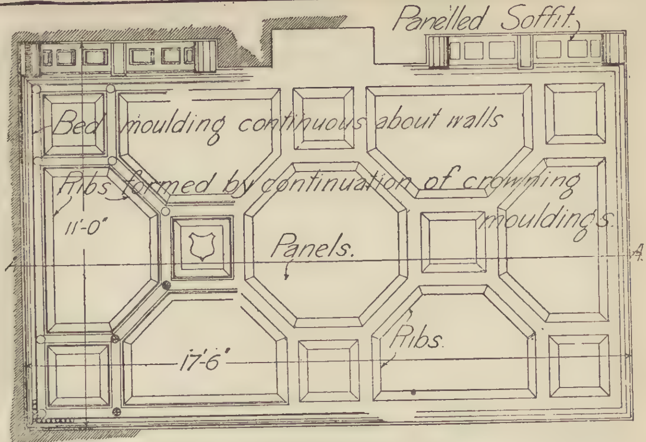


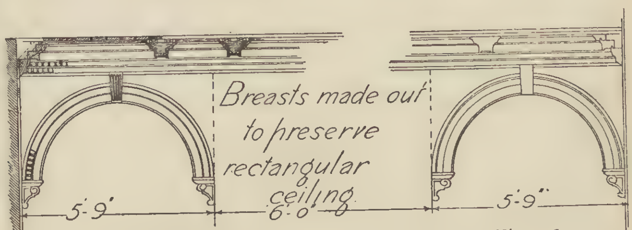
Fig. 461.

— Enlarged Section A.A. —

churches and halls being covered in this way. The particular construction depends upon whether the matchboarding forming the panels is placed parallel to the sides of the room or diagonally, forming herring-bone patterns, as shown



Plan of Coffered Ceiling. Fig. 462.



Sectional Elevation A A Fig. 463.

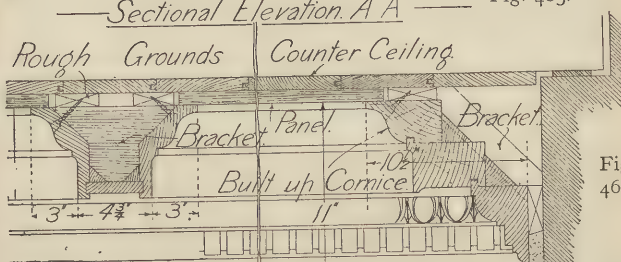


Fig. 464.

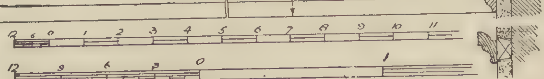


Fig. 465.

in figures 460 and 461. All that is necessary in the first case is to fix grounds to the undersides of the floor joists to which the matchboarding is fixed, the whole surface being covered, and upon this the ribs are fixed by screwing up in their required positions. In the second case, in order that a fixing may be obtained in any part of the ceiling instead of the ground it is more expedient to fix a counter ceiling, consisting of thin boarding, over the whole surface to be ceiled. The panels are then set out on the counter ceiling, and the pieces forming it are nailed up in position; the ribs are then fixed, covering the joints between the panels. In large ceilings there are usually two or three systems of ribs. Figures 460 and 461 show three systems of moulded members, the first of which forms the cornice. The primary ribs are then fixed, dividing the ceiling into large compartments, each of which is subdivided into panels by secondary ribs, as shown in figures 460 and 461. It should be noted that the moulding forming the secondary ribs forms the top member of the cornice and primary ribs, and the two members forming the primary ribs correspond to the upper two members of the cornice.

Coffered Ceilings.—These are usually employed in large ceilings in the Italian styles of decoration. They are formed, as shown in figure 462, by branching the upper members of the cornice from the corona to the drip in various directions across the ceiling space. The ribs are built up, as shown in figure 464, having a number of solid wood backings to which the mouldings at the sides are fixed, leaving the soffit as a panel free. The ribs are secured to rough grounds, fixed to a counter ceiling, formed of matched or plain boarding nailed to the underside of joists. The panels rest on the top members of the mouldings, and have rough grounds running at right angles to the direction of their grain, to which they are fixed along

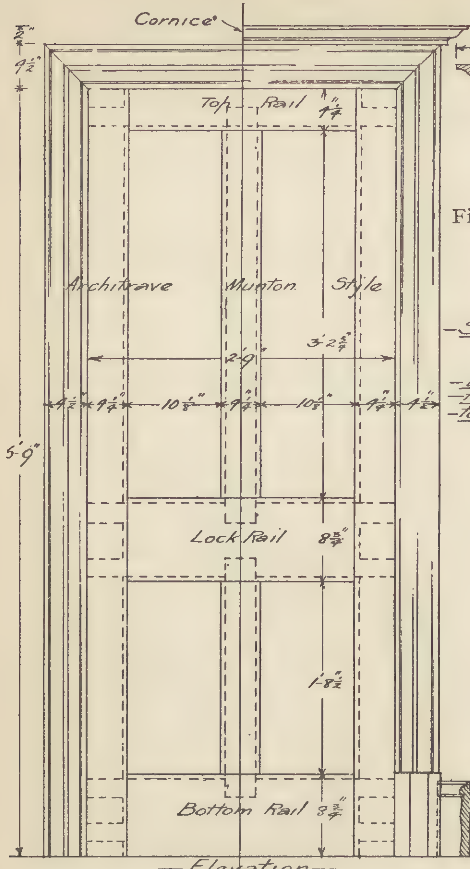
their centre line in order to allow them to freely shrink and expand. These panels are often highly carved, stencilled, or painted with various designs. The narrow panels forming the soffit on the level of the drip are also ornamented by paintings, and usually have the joint at the intersections covered by a boss or patera, as shown in figure 462.

In order to prevent projections such as chimney breasts from interrupting the design of the ceiling, the soffit at these parts is often lowered, and built or cradled out to form an arched head, as shown on figure 463, and thus leaving the ceiling rectangular in plan.

Secret Fixings.—It is usually considered undesirable to show any nail holes upon the surface of polished hard wood, architraves, skirtings, or finishings. These finishings may be fixed by means of screws fixed to and projecting at back of architrave or finishing, and fitting in slots in the backing, or dovetailed pieces are glued to the backs of the finishings, the backings being correspondingly grooved to receive them, care being taken always to have the grain of the dovetailed projection and the grain of the member to be fixed in the same direction, as, if not under varying conditions of dryness of the atmosphere, the piece fixed is liable to become loose or split.

Architraves and Overdoors.—Door linings are treated at length in the *Elementary Course*. Door openings are usually bordered with architrave mouldings to give them architectural effect. Five applications and modifications are shown in figures 466 to 478. These may be: first, a plain moulding mitred and fixed to the linings and grounds about the opening as shown in figure 466; secondly, they may be fitted with a base block and cornice mould as shown in figure 466. A section of the cornice and the method of fixing by screwing, the housing of the architrave to receive

Fig. 466.



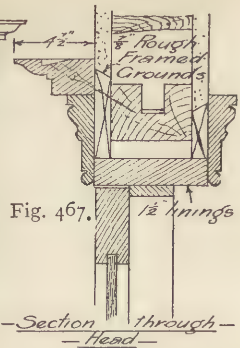


Fig. 467.

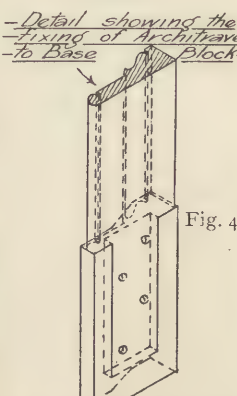


Fig. 468.

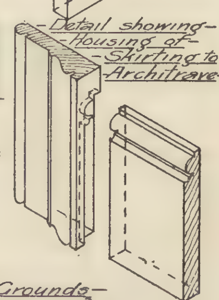
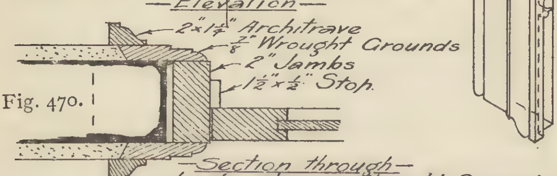


Fig. 469.

Fig. 470.



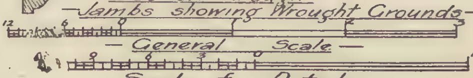


Fig. 471.

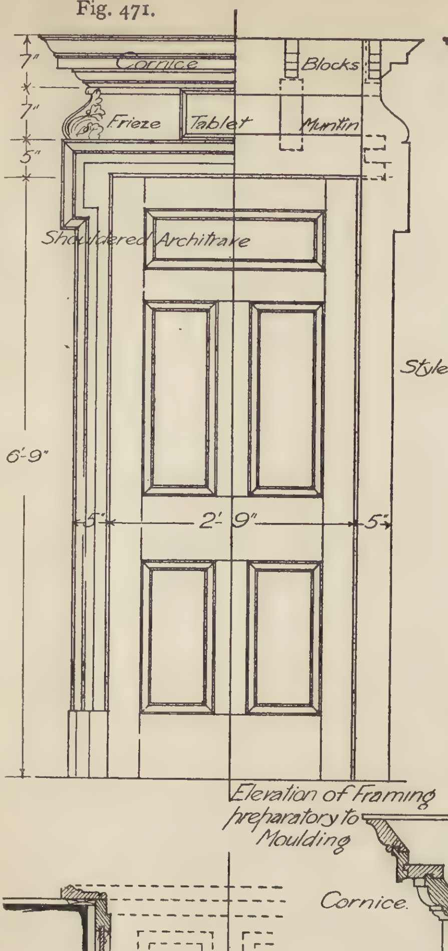
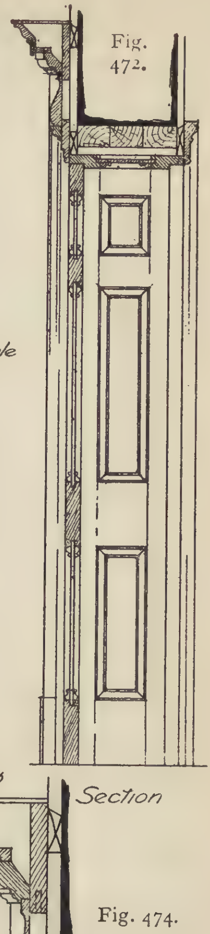


Fig. 472.



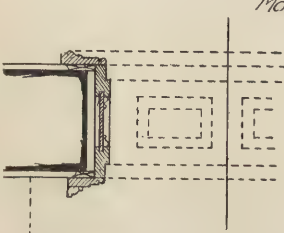


Fig. 473.

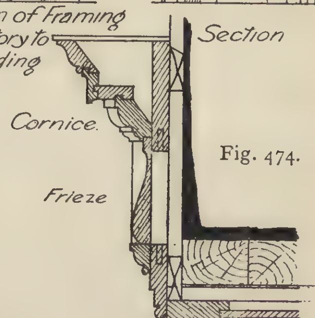
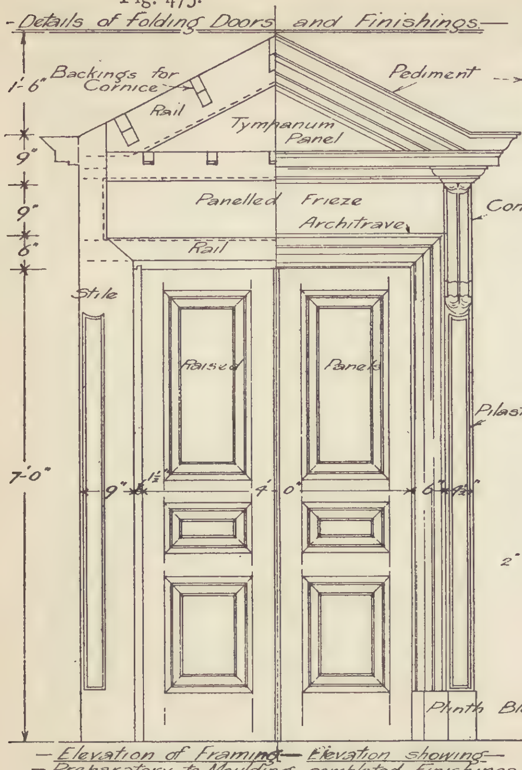


Fig. 474.

Fig. 475.



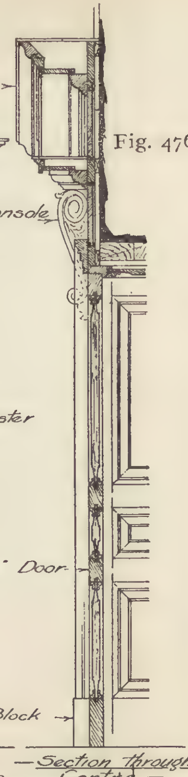
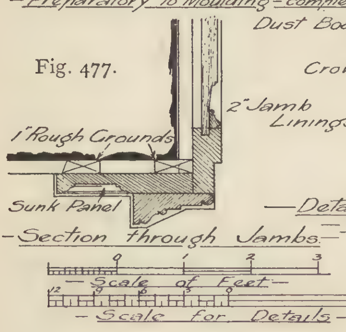


Fig. 476.

Fig. 477.



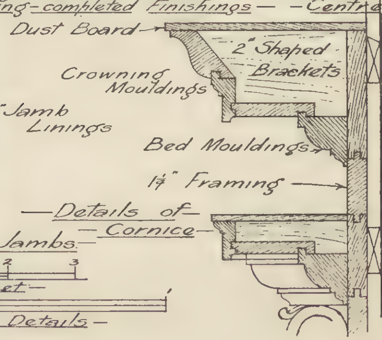


Fig. 478.

the skirting, the fixing of the architrave to base blocks are shown in figures 467 to 469 respectively; thirdly, figures 471 to 473 illustrate a shouldered architrave with frieze and cornice, with the frame upon which the architrave moulding is fixed, enlarged detail figure 474 shows the method of building up the frieze and cornice; fourthly, architraves with pilasters, entablature and pediment supported by consoles are shown in figures 475 and 476, with the arrangement of the frame upon which the mouldings are built. Figures 477 and 478 show enlarged details of the jambs and the building up of the cornice and pediment; fifthly, the architrave is displaced by a pilaster and entablature, as shown in figures 475 and 476.

Finishings to Fireplaces.—Fireplaces are frequently finished with a wood architrave with frieze and cornice, which latter serves as a shelf or mantel. Owing to the high temperature to which these are subjected, exceptional care should be taken in the framing and in the selection of thoroughly seasoned wood. Figure 479a shows the backing, and figure 479 the finished elevation; enlarged details showing the building up of the frieze, cornice, and jambs are shown in figures 482 to 484. The woodwork should not be placed in contact with the iron stove, but a marble slip, as shown in figure 481, should be inserted between them.

Doors.—Doors are classified under the following heads:—Ledged; ledged and braced; framed and braced; framed and panelled, the two latter comprise single and double.

The first three classes have been fully described in the *Elementary Course*. The fourth has been partially dealt with, so that the following is a continued description.

The following modifications of doors will be considered in this chapter:—Framed and panelled; single, folding, double margin, swing and sliding.

Fig. 479. Fig. 479a.

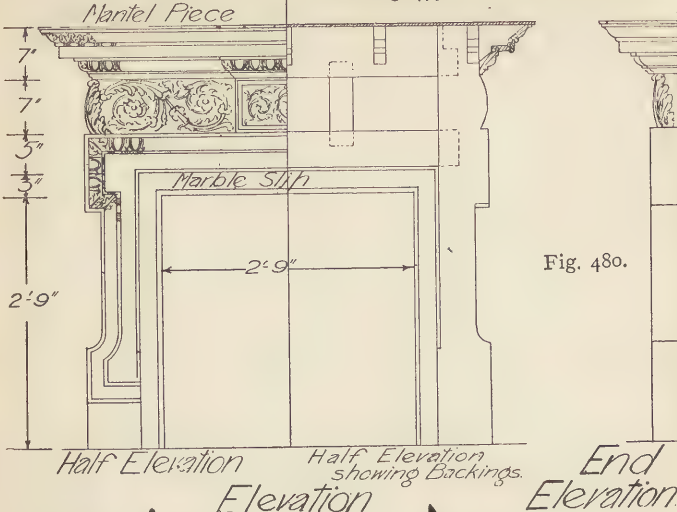


Fig. 480.

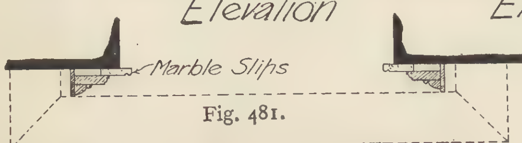


Fig. 481.

Plan of Fireplace

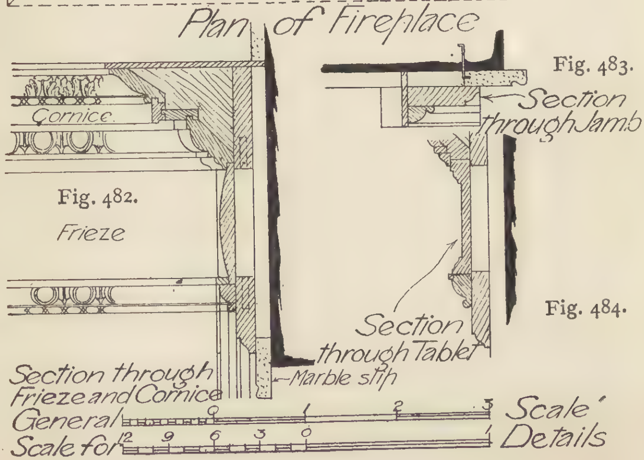


Fig. 482.

Fig. 483.

Fig. 484.

Figures 466 to 474 show two arrangements of single doors; the method of framing has been fully described in the *Elementary Course.*

Folding Doors.—Wherever the openings are over 3 feet 6 inches wide it is usual to arrange the door as two flaps, one hung to each side post. This lessens the excessive stress that would act upon the hinges, supposing it were hung in one flap, and requires less plan space for rotation. Figures 475 to 478 illustrate a pair of internal folding doors with three panels in each leaf, and figures 485 to 490 show doors with two panels in each leaf and with raised skirtings and dados. Figures 491 to 495 show swing doors for a lobby. Figures 496 to 499 show a pair of external folding doors. Figures 485 to 490 illustrate a pair of internal doors and finishings. Care must be taken in the disposition of all of the members, and arrangements must be made to allow of the wedging up of all the muntins, if such exist, which is not possible in the wide rails of the door shown in figure 888, *Elementary Course.*

This is done in the middle rail usually by making that member wide and in two widths. This renders it possible to wedge the tenons, the appearance of the joint being improved by a sunk moulding, or by continuing the dado rail across the door, as shown in figures 485 and 489. The bottom rail is treated in a similar manner by having two rails, and continuing the skirting across the door.

Swing Doors.—Doors in public buildings and shops are often required to open when pushed from either side; this is arranged by letting the door revolve upon centres fixed in the top and bottom edge. The top centre consists of two plates, from one of which a steel pivot projects, the other plate having a hole for the pivot to work in. The pivot is connected at the back of the plate to the end of one arm of a lever, the lever being connected to the plate

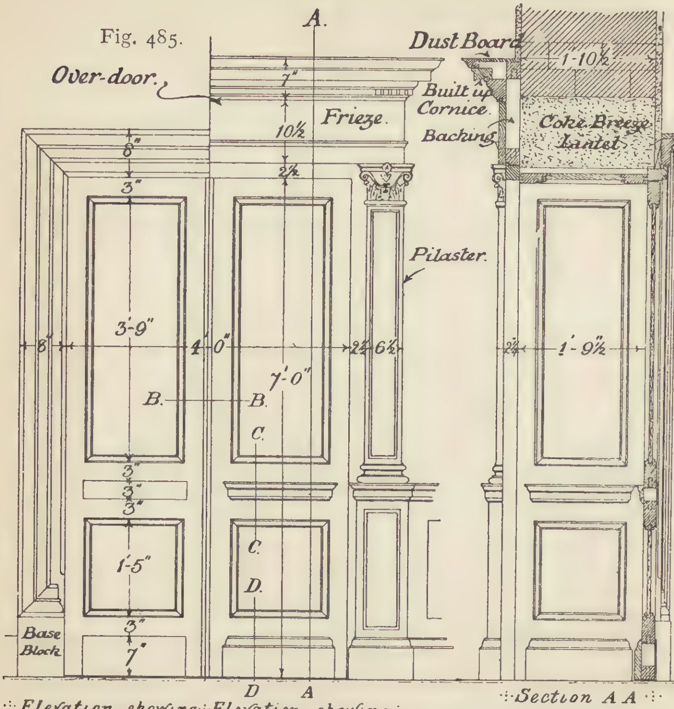


Fig. 488.

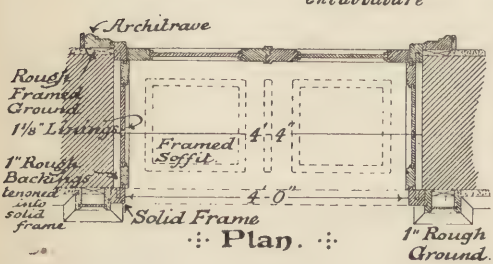


Fig. 487.

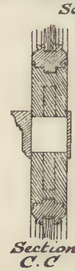


Fig. 489.

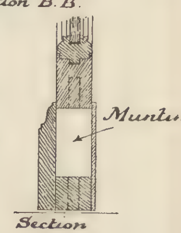


Fig. 490.

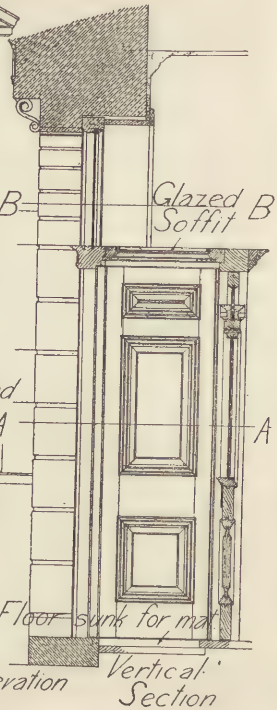
by a pin which acts as a fulcrum for it to turn upon. The other end of the lever is connected to a screw passing through to the face of the plate; this, on being turned, raises or depresses the pivot. This arrangement is necessary for erecting or taking down the door. This piece is fixed into the head of the door frame, and the slotted piece into the top edge of the door. The centre arrangement at the lower part of door consists of a metal box, which is let into the ground, and having a revolving square spindle projecting above; the box contains several strong springs, which tend to keep the projecting spindle in one position. A metal shoe, which encloses and is fixed to the bottom end of the hanging style, fits on the projecting square spindle, the latter, when left to itself, always tending to keep the door in a closed position. Both the vertical edges of the door must be rounded to the curves, the common centre of which is the middle point of the pivot upon which the door revolves, in order to allow the door to revolve, as shown in figure 493. A solid frame is used for these doors.

Figures 491 to 495 illustrate an application of swing doors applied to a lobby as used in business premises. The sides of the lobby are formed by the external doors, which, when the premises are open, are folded back at right angles to the front wall. The figures 492 and 493 illustrate how the hanging joints of the external doors may be made presentable. These doors are hung on centres without springs. The swing doors have their upper panels glazed, and are hung as previously described. The top of the lobby is constructed, as shown in figure 492, with a glazed soffit, to admit of the lobby being lighted from the interior.

Revolving Doors.—Revolving doors which are patented and known as the Van Kennel revolving door are largely employed at the entrances to vestibules of hotels, banks, clubs, &c., especially where the plenum system of ventilation

Fig. 491.

Fig. 492.



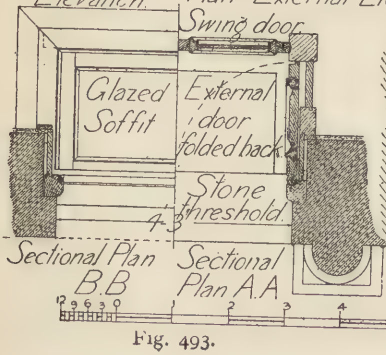


Fig. 493.

Fig. 494.

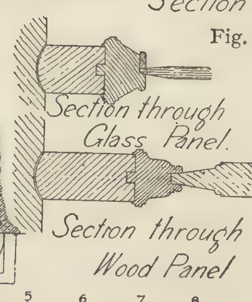


Fig. 495.

Fig. 496.

Fig. 497.

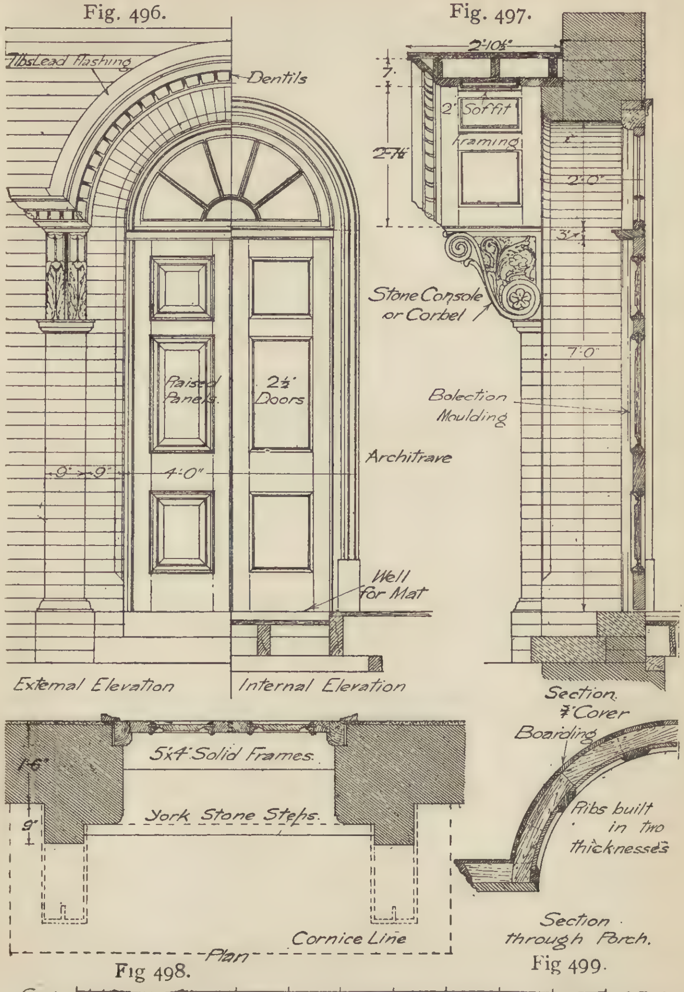


Fig 498.

Fig 499.

Figs. 496—499.

is in use; they consist of four vertical leaves or wings fixed at right angles to each other forming a cross in plan. The vertical edges of the four adjacent wings enclose and rotate about an axis. Two segmental pieces of framing with a soffit circular in plan form the enclosure, and are so arranged that at no time in the turnstile movement of the door is there any clear passage for a current of air to pass.

External Folding Doors.—A pair of doors hanging one on each post. Figures 496 to 499 show an entrance with a pair of folding doors and fanlight over. On the outside opening, a porch is shown arranged about the semicircular head to the opening; it is supported by stone consoles springing from a brick pilaster. The semicircular covering is constructed about three built-up ribs, as shown in sections, figures 497 and 499. The soffit is framed and panelled, a moulded front and $\frac{3}{4}$-inch cover boarding fixed in narrow widths to receive the lead covering above. The fixing is obtained by plugging the wall and nailing to the plug through the wall rib, the lower portion of the porch is dowelled to the stone consoles.

Double Margin Doors.—Where it is not convenient to have folding doors, and the opening is too wide relatively to the height to get one well-proportioned door, a double margined door is used, as shown in figures 500 to 500b. It consists of two doors, which are shot together at their meeting styles, and have a glued and tongued joint, a sunk bead or raised moulding being glued over the joint to hide it. In order to increase the strength of this joint, three or four pairs of hard wood folding wedges are glued, and fixed in mortices made in the meeting styles, and driven tightly home. In addition to this, in very wide doors an iron bar about $1\frac{1}{2}$ in. $\times$ $\frac{3}{8}$ in. extending over the whole width of the door is let in, and screwed in the top and bottom

edges. In constructing the door, the rails must be wedged in the meeting styles first, then the meeting styles joined together, after which the panels are inserted, and the

Fig. 500.

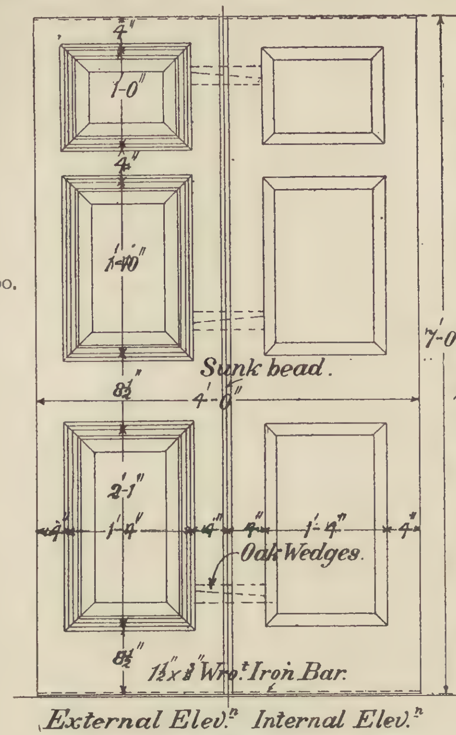


Fig. 500a.

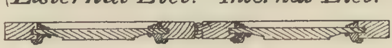


Fig. 500b.

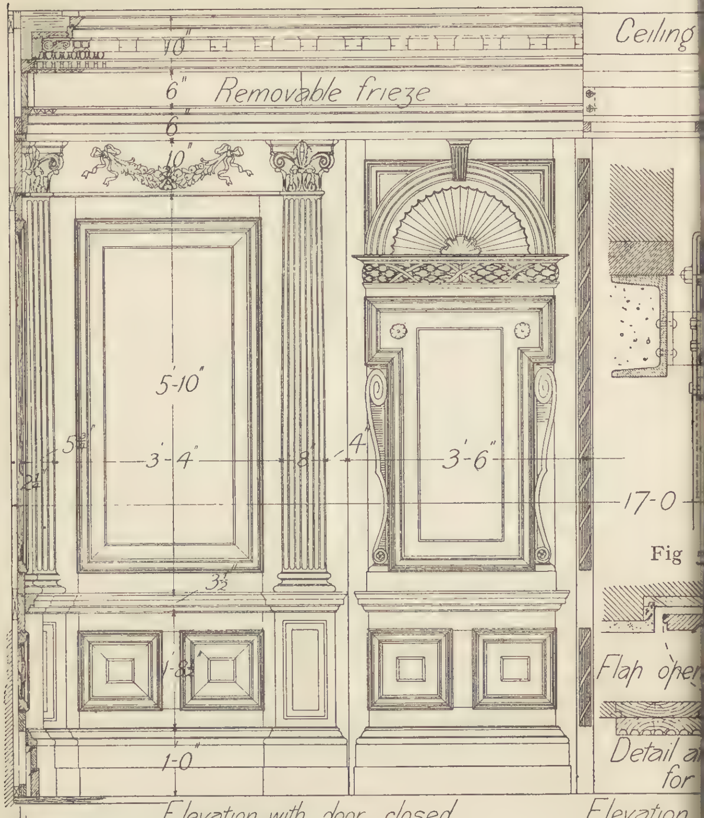
outer styles are glued and wedged, and the door finished in the ordinary way.

Sliding Doors.—This method of hanging is employed for wide doors, where the space required for them to revolve on one edge is not available. It is chiefly employed for

factory doors or gates, but often for residential buildings. The apparatus is as follows:—An iron bar, sufficiently strong to support the doors without deflection, is fixed to the wall, usually by having the two ends turned at right angles and built into it. If there is to be a pair of doors, the bar is also supported in the centre by a piece of iron of similar section, fixed to it at right angles, and projecting into the wall at that part. The bar is rounded at the top edge; and on this wheels with a hollow edge revolve, the wheels being fixed at their centres with iron straps connected to the doors below. Where the appearance of the doors is a matter of consideration, the straps must be fixed to the top edge of the door; but for factory and that class of door, where strength is chiefly required, the straps, which are in pairs, are let into or fixed upon the face of the doors on each side, bolts being passed through the two straps and the door.

Figures 501 to 506 illustrate the application of sliding doors for residential purposes. It is considered necessary that the doors when open should slide into a compartment made to receive them behind the wall framing. In high-class work, where there are large projections on the face of the door, as in figure 501, a large space is required behind the wall framing in order to prevent the unsightly appearance of a large opening, and also, to form a finish, a vertical flap is provided which automatically closes behind the doors when these are shut. This arrangement is shown in detail figure 506, and consists of a rack and pinion fixed to the top of door and flap. When the door is opened it is pushed back beyond the flap and the latter is closed by hand. Figures 504 and 505 show enlarged details of the runner and rollers. Where the doors are heavy it is advisable to use bulb iron for the runner to prevent deflection. Figures 504 and 505 illustrate runner secured to channel forming the lintel in the centre and resting at its two ends

Fig. 501.



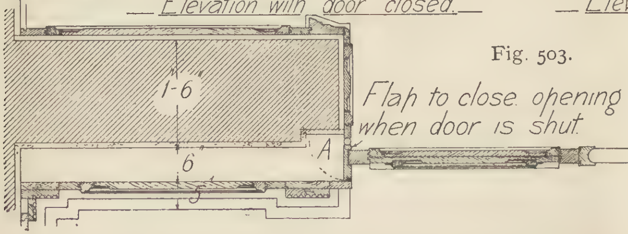


Fig. 503.

Fig

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Fig. 502.

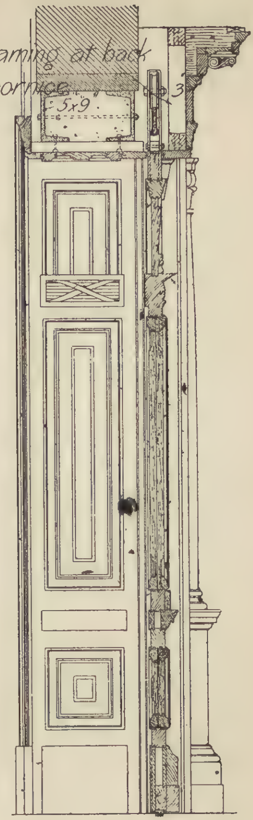


Fig. 505.

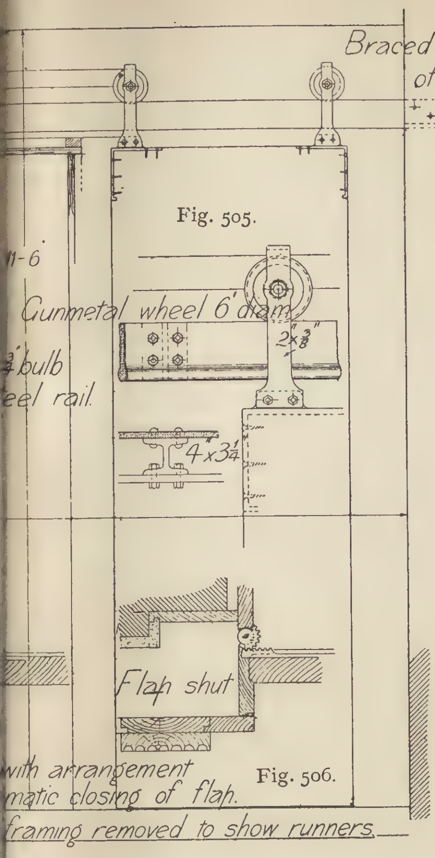
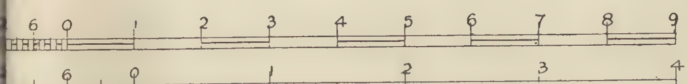


Fig. 506.



—506.

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Fig. 507.

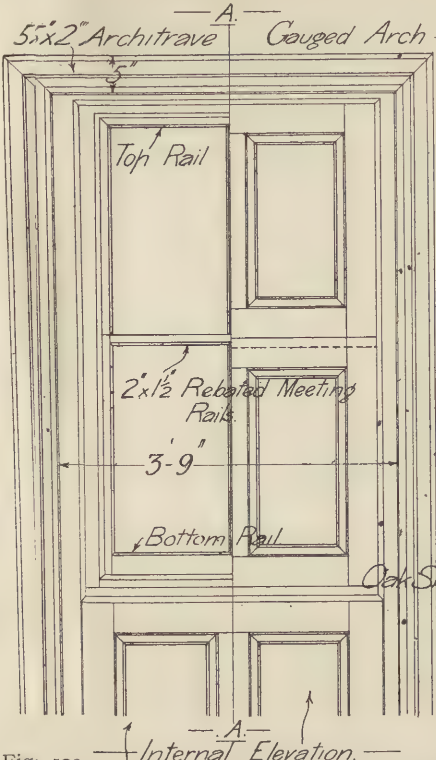


Fig. 508.

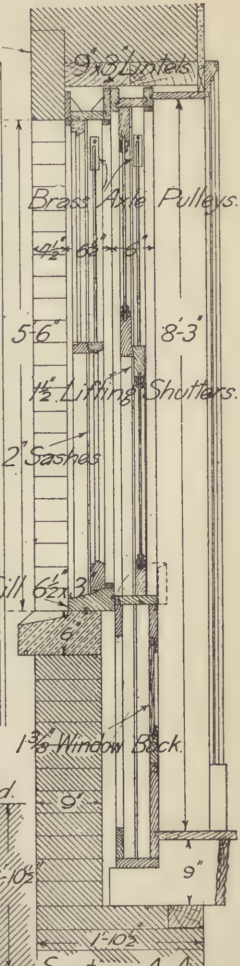
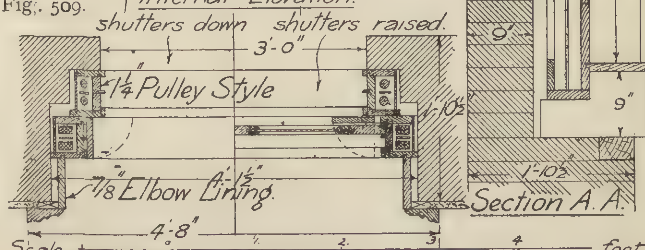


Fig. 509.



upon the cross walls, having angle irons riveted to it to increase the bearing surfaces, thus leaving a clear space between the bearing points and enabling the strap supporting the door to pass down both sides of runner. The detail of roller is shown, but it should be noted the larger the wheel the easier and quieter is the action. The frieze is shown removable in order to bare the rollers in the event of repairs being necessary. A small groove is let into the floor, and a small tee iron is sunk in bottom rail of the door and runs in the groove, forming a guide for the bottom of the door.

Casement Lights with Sliding Fanlight.—The ordinary forms of sashes and frames for windows have been dealt with at length in the *Elementary Course.* Of late years a combination of casement and sliding sashes has been introduced in casement sashes with a fanlight. It is often inconvenient to have the fanlight opening inwards on butt hinges, and it is impossible in frames circular in plan; under these conditions they are made to slide vertically in a similar manner to a hung sash; the frame is constructed as shown in figures 510 to 515.

Window Linings. — Window linings may be plain or framed, the latter being employed when the walls are thick enough to allow of them being so treated; the method of fixing is shown in figures 936 to 938, *Elementary Course.* Windows on or near the ground floor often have the linings arranged as shutters for protection.

Shutters.—There are two kinds of shutters used generally for windows, known as sliding and boxing shutters.

Sliding or Lifting Shutters consist usually of two or more panelled frames $1\frac{1}{4}$ inches thick, arranged to slide vertically in grooves formed in cased frames, the latter being constructed similarly to the double-hung sash frames, the panelled frames working in the same way as the sashes.

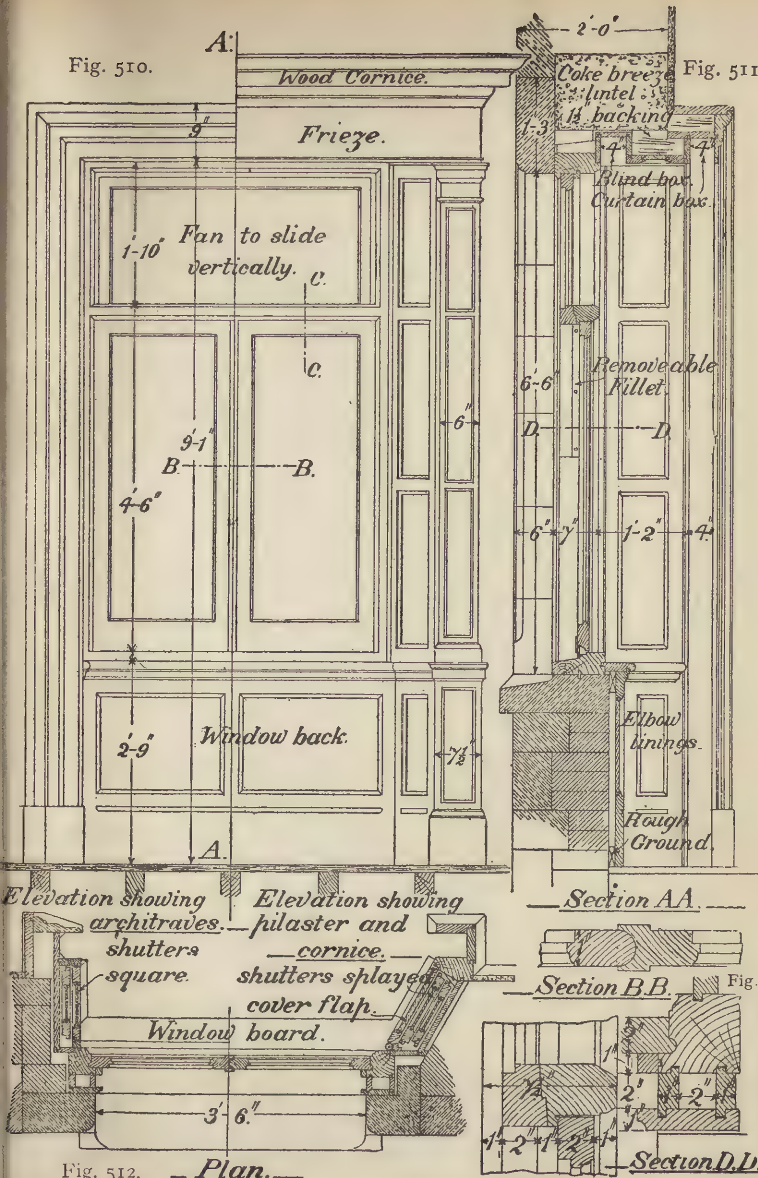


Fig. 510.

Fig. 511.

Fig. 512.

Fig. 513.

Fig. 514.

Fig. 515.

When the shutters are closed, they are pushed down behind the window back, and a flap closed down upon them; when open they overlap each other where they meet, and cover the whole window area. Figures 507 to 509 show fully the method of arranging them. The frames are fixed directly to the inside of the window frames, and the window linings and finishings on the inside of these as before.

Boxing Shutters.—These, as shown in figures 510 to 515, have been dealt with in the *Elementary Course.* The shutters may be arranged at right angles to the window plane, or in thick walls they may be splayed to more efficiently distribute the light. These two methods are shown in figure 512.

When the shutters cover the window opening, the boxing presents the appearance of a dark recess; this, in good work, is considered objectionable, and in this case another frame, termed a cover flap, hung with butts to the architrave, is arranged to cover the recess when the shutters are open, and also to cover the shutters, which fold up behind it when closed, as shown in figure 512.

Finishings.—Window openings are usually finished by having an architrave moulding mitred about them; the architraves are sometimes very wide and richly carved. Where this is done, a space is usually arranged beneath them, as shown in figure 511, to contain curtains; the fittings for these and their edges being contained and enclosed by the architrave. Curtains, where fixed in the ordinary way, usually cover the architrave. Instead of ordinary architraves, pilasters with a frieze and cornice, as shown in figure 510, are often adopted where the door openings in the same room are treated in that way.

Skylights are sashes fixed on pitched roofs, as shown in figures 516 to 522, primarily to light the space below.

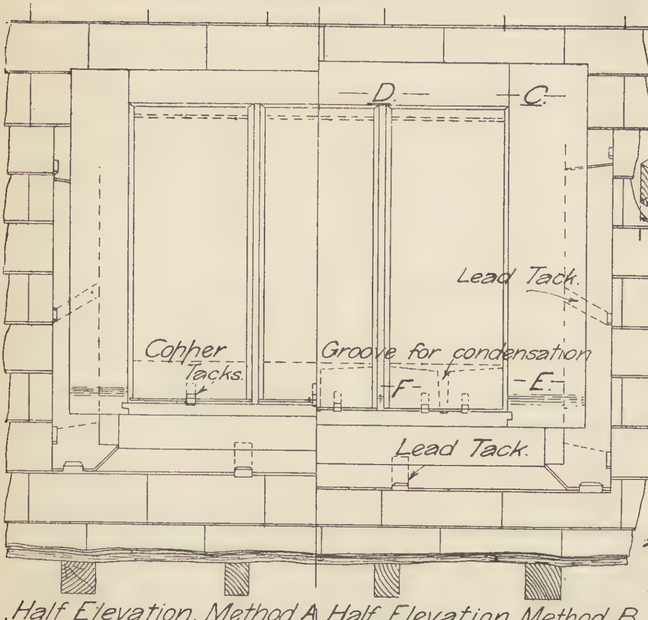
They are also often made to open for ventilating purposes, the process of fixing being as follows:—The common rafters of the roof are trimmed to the size required, and the roof boarding is fixed, upon which is spiked or screwed a rough wood curb dovetailed at angles, which should be at least 6 inches deep and flush with trimming and trimmed rafters, these are then cased with wrought and beaded linings, rebated to receive plastering or boarding. In most cases, the wrought and beaded curb lining is made at least 2 inches in thickness, grooved and tongued at angles, and the rough curb is omitted. This construction is more economical, is sufficiently rigid, and renders it possible to reduce the width of styles, top and bottom rails. The curb is covered with lead on the outside to render it watertight.

The skylight is placed on the top of the curb to which it is hung, extending over it for at least 2 inches on every side, and being throated on the underside on all four edges. The underside of the top edge often has a fillet about 1 inch in thickness fixed to it, projecting below the top edge of the curb, as an extra precaution against water finding its way in at that part. The sash projects over the curb on its inner edge about $\frac{3}{4}$ inch on the sides and top rail, and about $1\frac{3}{4}$ inches on the bottom rail, the extra width here being required for fixing the apparatus for opening the sash. The sash is constructed slightly differently from other sashes, the variations being as follows:—The top rail is grooved instead of being rebated for the glass. The bottom rail is made of a less thickness than the remainder of the sash, the upper surface of the rail being level with the rebate to allow the glass to run over it; the top upper edge of the bottom rail is rebated to form a gutter to collect condensed vapour, this being carried off by transverse grooves, as shown in figure 522. As an alternative to this, the whole surface of the rail is sometimes kept below the rebate, as shown in figure 521.

Lantern Lights.—These are an improved form of skylight; they are used chiefly for flat roofs, and also on the ridges of pitched roofs, and consist of a box-like arrangement, being square, rectangular, or polygonal in plan. They usually have sides vertical, as shown in figure 523, but sometimes are arranged in an inclined position. The following is the method of building an ordinary lantern on a flat roof:—The roof timbers are cut and trimmed about the required opening; the boarding is then laid on the roof. A curb is then constructed about the opening, this being at least 6 inches in height; the curb is usually prepared from 6 in. × 4 in. fir bevel halved or dovetailed at the angles, or if the roof is of concrete and steel the curb may be arranged as shown in figure 525; the inside linings, which may be plain or framed, are now fixed, the top of the linings being level with the top of the curb. A moulding is fixed about the top of the lining, having a groove taken out of its top back edge. The lead work of the roof is laid, being turned up about the curb; a flashing is placed on the curb, being nailed to the edge of the moulding mentioned, and dressed down over the curb. Small grooves are taken out of the curb at about 3 feet intervals, into which the lead flashing is dressed, these forming ducts to carry off the condensed vapour; or in the case of a steel curb, the ducts are cut out of the underside of the sill, as shown in figure 525. An alternative method of carrying off the condensation is to work a moulding on the inside of the sill, having a gutter worked on the top, with ducts bored through the sill, as shown in figure 523. The sides of the lantern are now placed on the curb; they consist in a rectangular light of four solid frames, each angle post being common to two frames, or as an alternative method four frames may be constructed which are connected at their angles by means of handrail screws through the head and sill, as shown in figure 530, this method being preferable for

Sky

Fig. 516.



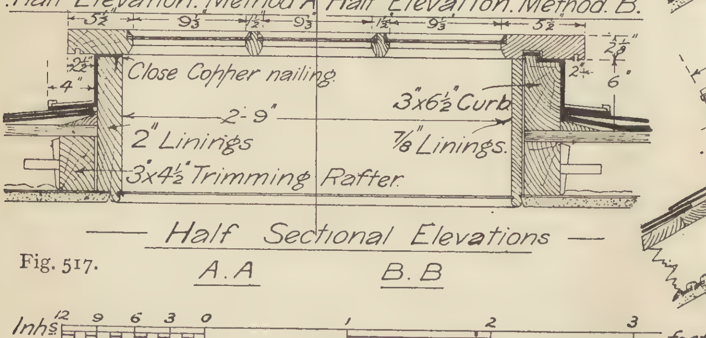


Fig. 517.

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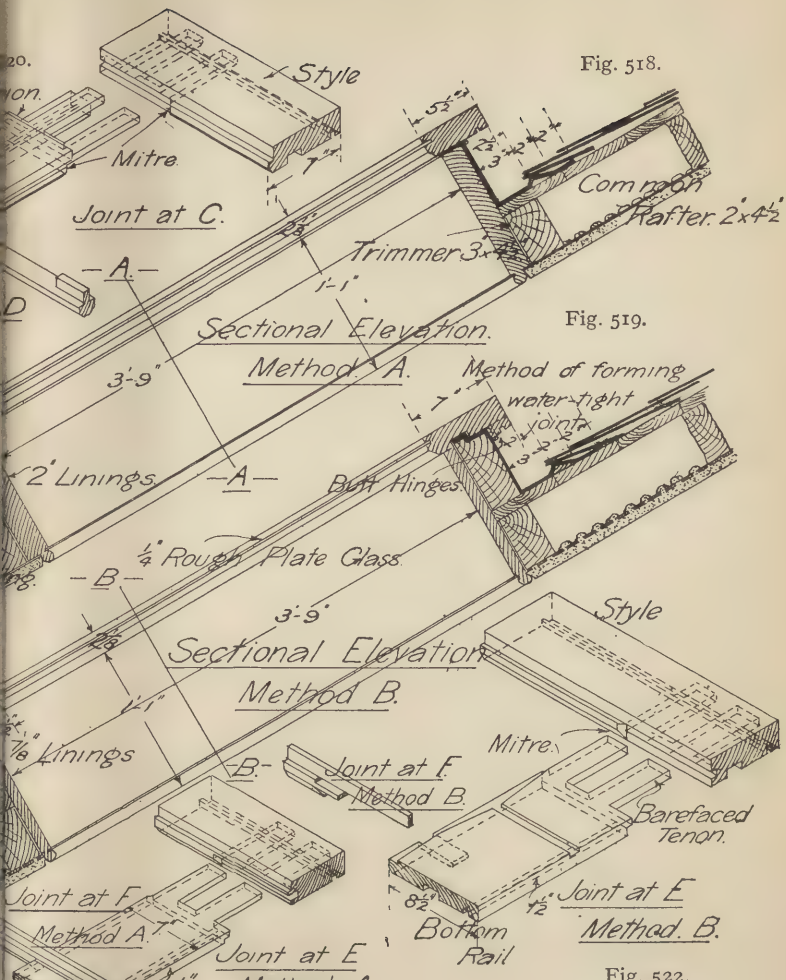

Fig. 518.

Fig. 519.

Fig. 521.

Fig. 522.

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Fig. 523.

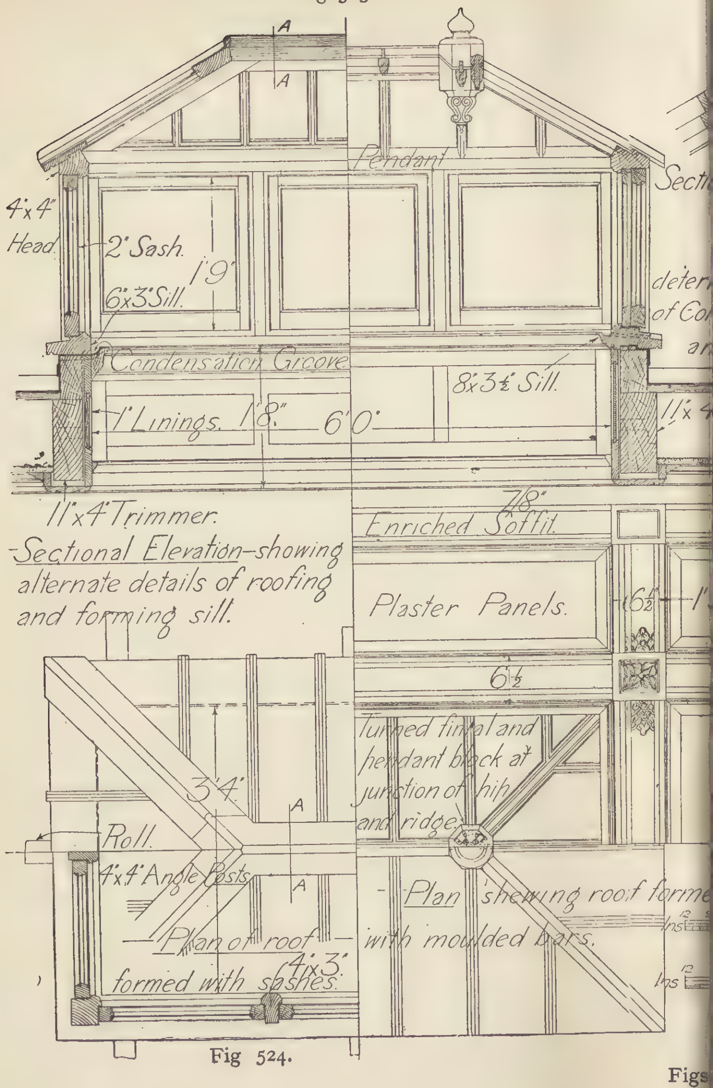

Fig 524.

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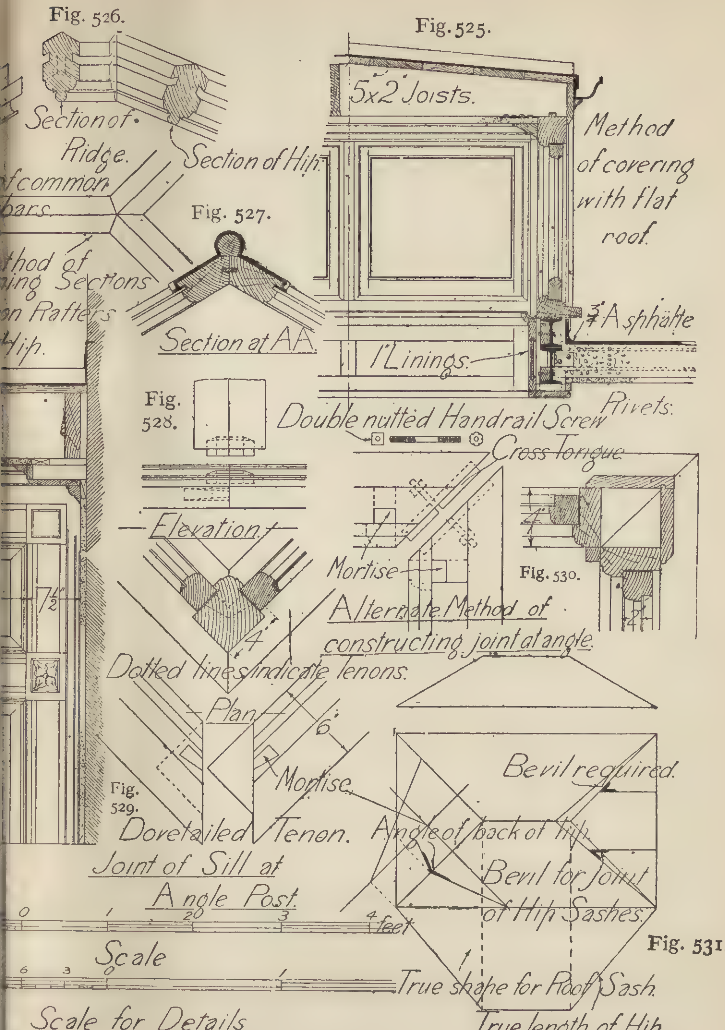


Fig. 526. Fig. 525. Fig. 527. Fig. 528. Fig. 529. Fig. 530. Fig. 531.

—531.

[Between pages 578 and 579.

large frames, being more portable and easier to hoist in position without the fear of racking, and sometimes intermediate mullions are added; the sill is usually of oak, being double sunk and throated. It is made to project at least 1½ inches in front of the curb; the inside of the lantern is kept flush with the inside linings, as shown in figure 523.

There are three general methods of roofing lantern lights. First: They may be covered with four sashes constructed similarly to skylight sashes, and mitred together at their angles, and forming a hipped roof, the joint being covered with a roll, and after glazing the top rail is covered with lead, as shown in figure 527. Secondly: They may have a hipped roof, constructed of moulded bars. The hip, ridge, and other bars will be of different sections, owing to their varying inclinations. The method of obtaining the sections is shown in figure 526. The hips and ridge may be mitred and dowelled together, but a better method is to frame them into an octagonal block, which shows as a finial outside and a pendant inside, as shown in figure 523; the common and jack bars are framed into the ridge and hips, as shown in figure 524. Thirdly: They may be covered with a flat roof, in which case light joists having a fall in both directions are placed parallel to two of the sides, and are boarded and covered with lead. A cast-iron gutter is placed about the roof, as shown in figure 525, and a downpipe at one angle to carry off the rain.

Figures 523 and 524 show methods of arranging finishings for the bottom edge of linings. Figure 531 illustrates methods of determining bevels of the various angles of a hipped covering.

Shop Fronts.—The external glazed wood-framings fixed on the ground floor of a building, designed and arranged for the display of goods for sale, are termed shop fronts. Shop fronts are divisible into three parts: (1) The upper

part, consisting of the frieze and the cornice; (2) the sash; (3) the stall board, and stall board framing.

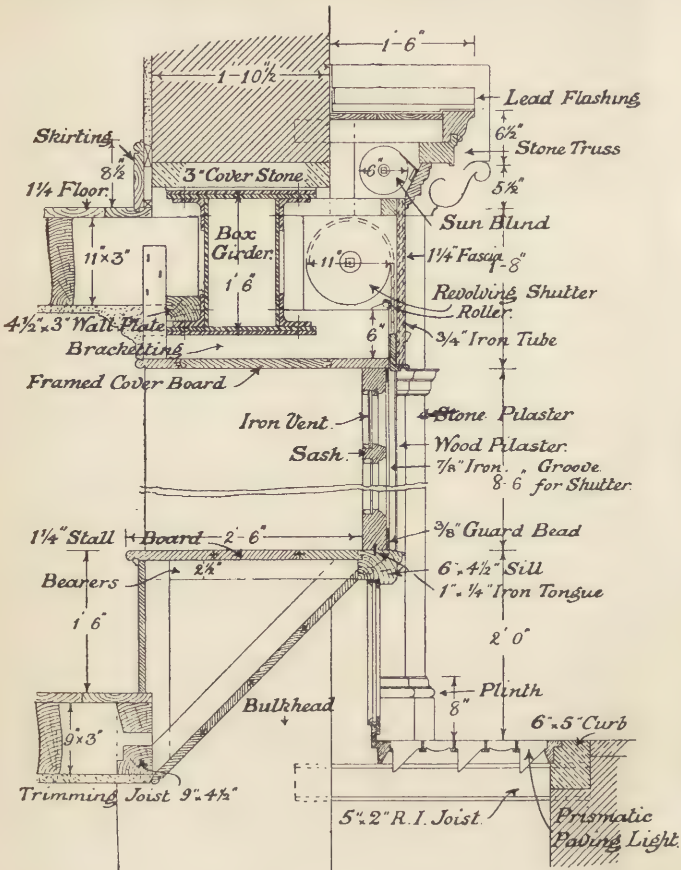


Fig. 532.

They may be classed under three general heads, according to the arrangement of the shutters, as follows:—(1) Those without shutters; (2) those with wood-framed

shutters ; (3) those with revolving shutters. The difference in the three classes applies to, and affects mainly the upper part of the front, special construction being needed here to contain or receive the shutters at that part.

Figure 532 shows an example of the third class with revolving shutters, a sun blind also being arranged in the cornice; this is the most difficult case of the three, and a full description of this, which is given, will render unnecessary any explanation of the other two.

The fascia and cornice is the first part to be fixed, being secured to bracketing fixed into the face of wall, about the bressummer, as shown in figures 532 and 533. Specially strong brackets have to be fixed to support the revolving shutters, about 7 feet apart, this being the usual length the shutters are made. The shutter consists of a number of narrow wood strips, connected with each other by thin metal bands or hinged joints, which arrangement makes it possible for the shutter to be folded up.

The shutter is fixed at one edge to a hollow cylinder, containing a strong spring fixed to a central spindle projecting at each end of the cylinder; the projecting parts are made square, being placed in a socket screwed to the strong brackets already mentioned; the central spindle does not revolve, only the hollow metal cylinder to which the bands passing through the shutter are fixed; when the shutter is opened the spring is strained, and when closed it tends to regain its normal condition, thus making it easy to lift the weight of the shutter. The revolving shutters slide along vertical iron grooves, screwed into the side of pilasters fixed at both sides of the shop front; at intermediate distances between the two outside pilasters, upright members with grooves on their two edges, termed loose pilasters, as shown in figure 534, fitted with studs and plates in their upper and bolts at their lower ends, are placed directly below the bracket supporting the shutters to

secure the free edge of the shutters when open. When the shutters are closed these pieces are taken down.

The fascia board is fixed to the brackets to which the shutters are hung. There is a tendency for the fascia to cast when very wide; this is prevented by boring a hole at intervals of about 3 feet apart through the whole width of the board, and passing round iron bars through it, thus allowing it to shrink without casting.

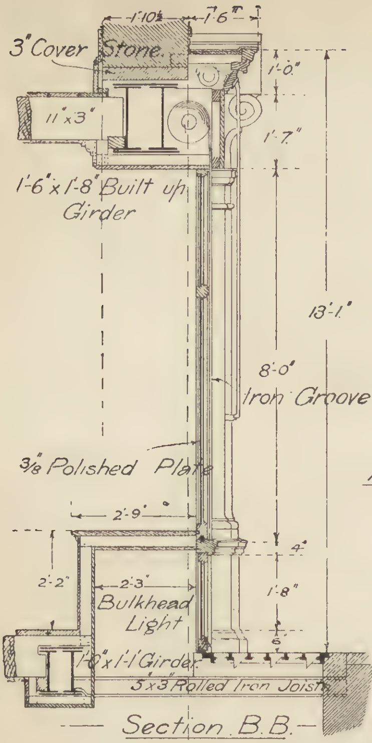
The stall board framing is now fixed in the correct position below the fascia. On the top of the stall board framing a sill is fixed, as shown in figures 532 to 536. In many cases where there is a basement, a sash is substituted for the framing; this also is sometimes dispensed with, bars only being used. Figures 532 to 536 show examples with sashes and prismatic pavement lights. The sashes are then erected on the sill, between which and the cover-board (that is the soffit below the girder) it is accurately fitted and fixed. About the sash a thin fillet, rounded on one edge, termed a guard bead, is fixed; this acting as a scribing fillet to make a good finish and close joint about the sash, and also to prevent the shutters rubbing against the sash.

Figures 533 to 536 show complete working drawings for a double fronted shop front complying with the London County Council regulations.

The regulations of the London County Council require:—

Projection of Shop Fronts.—In streets or alleys of a width not greater than 30 feet, any shop front may project beyond the external wall of the building to which it belongs for 5 inches and no more, and any cornice of any such shop front may project 13 inches and no more; and in any street or alley of a width greater than 30 feet, any shop front may project 10 inches and no more, and the cornice may project for 18 inches from the external walls, but no more, over the ground of the owner or the builder.

Fig. 533.



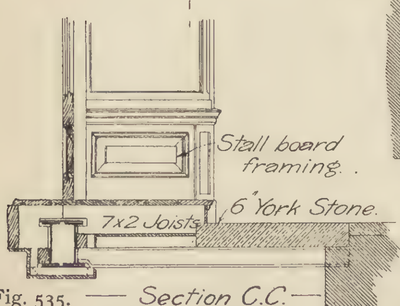
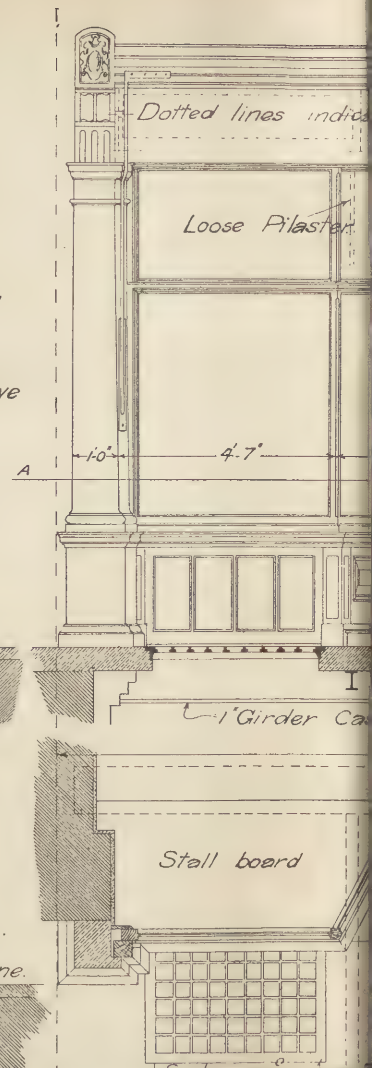


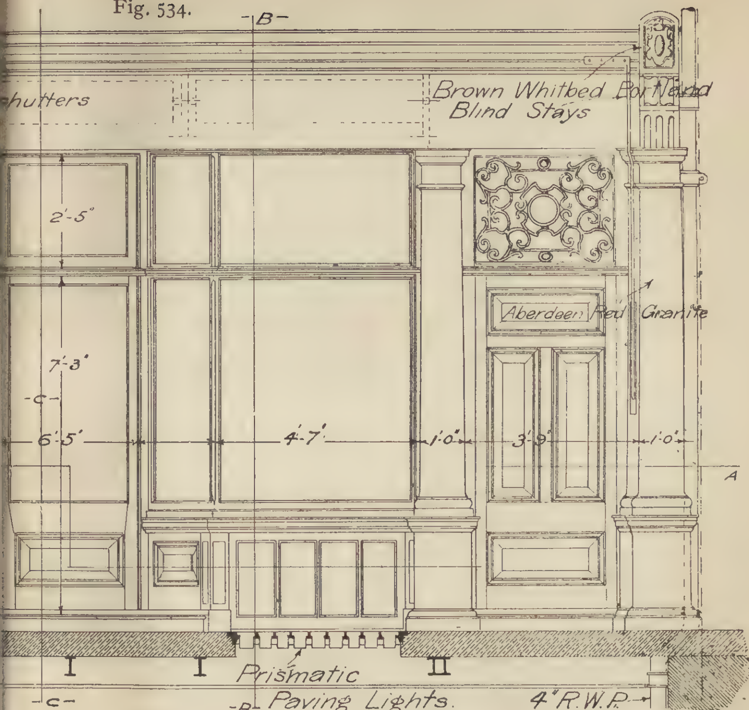
Fig. 535.



Figs

FRONT.

Fig. 534.



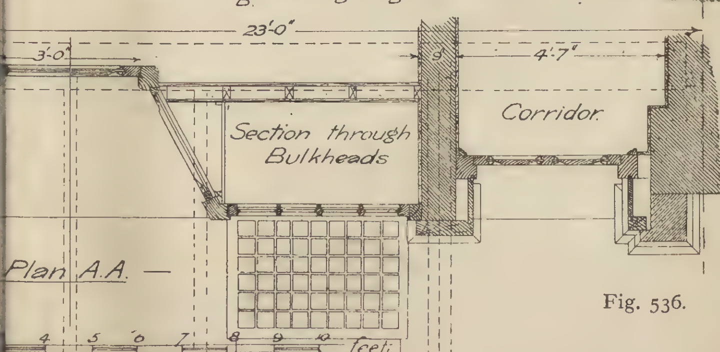


Fig. 536.

—536.

[Between pages 582 and 583.

Woodwork of Shop Fronts.—No part of the woodwork of any shop front shall be fixed higher than 25 feet above the level of the pavement of the public footpath in front of the shop. No part of the woodwork of any shop front shall be fixed nearer than 4 inches to the centre of the party wall where the adjoining premises are separated by a party wall, or nearer than 4 inches to the face of the wall of the adjoining premises where the adjoining premises have a separate wall, unless a pier or corbel of stone, brick, or other incombustible material 4 inches wide at the least be placed as high as such woodwork, and projecting throughout an inch at the least in front thereof between such woodwork and the centre of the party wall or the separate wall, as the case may be.

CHAPTER XIV.

STAIRS.

Materials.—Stairs are made in stone, concrete, ferro-concrete, brick, iron, and timber; all but the latter two have been already treated.

Iron Stairs.—Iron stairs are used for internal and external constructions, where there is a minimum of space to be occupied, and where the least obstruction to light and air, and a measure of fire-resistance and economy are chiefly required, such as where the internal plan space is small, spiral steps are used, and for external stairs to buildings; they are not combustible, but they are slippery when worn, and are not much used for other purposes.

Planning of Stairs.—Buildings should be designed for and provided with convenient staircases, and the planning of the stairs considered as of primary, and not of secondary importance.

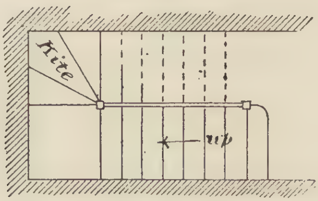
Design of Stairs.—Properly designed stairs should (*a*) be well lighted and ventilated directly from the exterior; (*b*) have the approaches convenient and spacious; (*c*) have the headroom in no case less than 7 feet measured vertically; (*d*) have a clear width between the strings of the straight portion of flights kept at all turns, landings, and approaches; (*e*) have the stairs of a convenient and easy pitch; (*f*) not have a landing between two adjacent flights, the centre

lines of which are in one straight line, with a length less than the width of the adjoining stairs; (*g*) have winders (if any at all) at the bottom and not at the top of a flight; (*h*) have not less than four steps in each flight.

The non-compliance with these conditions has resulted in numerous accidents.

Technical Terms.—Stairs.—Timber stairs or steps consist of a number of wooden blocks or casings fitted into, or resting upon inclined beams called strings and carriages, which distribute the load upon the main members of adjacent floors.

Fig. 537.



DOG-LEGGED STAIR.

The trimming of floor joists to form well holes has been shown in the chapter on Floors, *Elementary Course.*

Staircase.—The chamber containing the stairs is usually known as the Staircase.

Tread.—The upper surface of a step upon which the foot is placed.

Nosing.—The exposed edge of the tread, usually projecting and moulded.

Riser.—The face of the vertical member directly between the nosing of an upper and the back edge of the lower step.

Fliers.—Steps retangular in plan.

Winders.—Steps tapering in plan. Those fitting into a wall angle, as shown in figure 537, are termed kite winders.

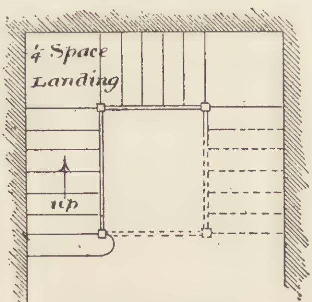
Going.—The horizontal distance between two riser faces.

Rise.—The vertical height between two tread faces.

Flight.—A series of steps without a landing.

Landing.—The level platform at the top of a flight between floors.

Fig. 538.



OPEN NEWEL STAIR.

Half-space Landing.—A rectangular landing extending across the widths of two flights and against one edge, of which both flights abut, and on which a half turn is made.

Quarter-space Landing. — A rectangular landing, the breadth and length of which are of the dimensions of the two abutting flights, as shown in figure 538, and on which a quarter turn is made.

Line of Nosings.—An imaginary line parallel to the strings and tangential to the nosings. It is useful in the construction of handrails, giving the line with which the under-surface of the handrail should coincide.

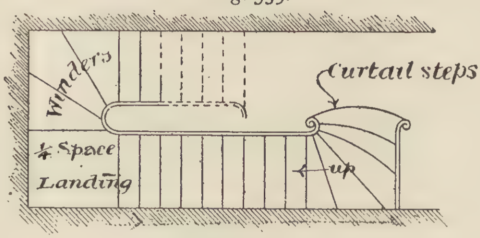
Newels.—Posts forming the junction of flights of stairs with landings or other flats.

If the outline plan of newel stairs enclose a space or solid they are known as open or solid newels respectively.

Straight Stair.—Flight or flights of parallel fliers that may be seen from top to bottom, the centres of which being in the same straight line.

Open Newel.—Stairs, the turns of which have newels and enclose a well.

Fig. 539.



GEOMETRICAL STAIR.

Dog-legged Stair.—A flight of stairs with abrupt angular turns, usually about a newel, and often with winders and landing. The name is given owing to its supposed resemblance to a dog's hind leg, as shown in figure 537.

Geometrical Stair.—Stairs having continuous strings or handrail, and usually compassing a well. Typical examples of those rectangular and circular in plan are shown in figures 539 and 540.

Solid Newel.—Stairs radiating from a solid central newel, circular or rectangular in section.

Handrails.—A rounded or moulded member, as shown in figure 556, following generally the contour of the nosing line, the upper surface of which is usually 3 feet, minus half-a-rise above the nosing line above stairs, and 3 feet above

level platforms. These are usually placed over the outer strings, but in wide staircases should be placed on the wall side also, as shown in figure 381.

Ramp.—A plane curve without change of direction; it occurs in handrails, as shown in figure 544, and in those parts of strings over windows and landings.

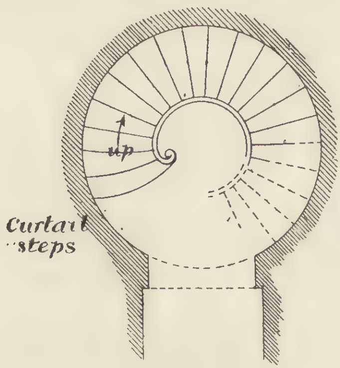


Fig. 540.

Swansneck.—A plane continuous curve, such as would be formed by joining a concave with a convex ramp, as shown in figure 544.

Iron Core.—The iron band about $\frac{3}{16}$ inch to $\frac{1}{4}$ inch in thickness, used in the handrail of geometrical stairs to strengthen the curved handrail and to which the balusters are fixed. Iron cores, as shown in figure 543, are used in all stairs having iron balusters.

Balusters.—Vertical members between the handrail and strings to stiffen the handrail and prevent persons falling through.

Balusters should be tenoned to close strings and handrails, as shown in figure 541, and dovetailed to the treads of cut strings, the return moulding of tread being planted,

mitred, with returned end and covering the dovetail, as shown in figures 553 to 555.

There are usually two balusters for each step of a cut string, as shown in figures 553 to 555, and in close strings they are placed about 4 inches apart.

Balustrade.—The framed fence formed by strings, handrails, and balusters, as shown in figure 544.

Curtail Step.—A step, the outer end of which follows the plan of a spiral scroll, and under which it is directly situated, as shown in figure 558.

Bull-nose Step.—Steps with rounded ends, which may be quarter round, as in figure 549, or half round, as in figure 538.

Built-up Steps.—Wooden steps are usually built up of a number of comparatively thin casings, dressed only on the seen faces. Each step takes a bearing on at least two or three carriages, or rough, or dressed strings, the soffit of which is plastered, as shown in figure 548, or it may be boarded. The space enclosed is sometimes objected to as being unsanitary. Figure 542 shows that by dressing all seen surfaces of steps and carriages, which are made usually thicker than the thin casings the void may be dispensed with.

Strings.—The members receiving the ends of the steps to which they are usually housed and wedged, as shown in figure 541, are known as close strings. Strings adjacent to walls are known as wall strings, the remainder as outer strings. If instead of being housed and wedged to the outer strings, steps are fitted, as shown in figures 554 and 555, they are known as cut and mitred. The latter have thin shaped brackets planted on outer strings, and one edge mitred to riser for effect, as shown in figure 554.

Pitch of Stairs.—It is found in practice that the best pitch for stairs is that inclination which by twicing the rise

and adding the going equals 23. This agrees very well with the French theory: The labour of moving vertically is about twice that of moving horizontally, if the average human stride be taken as 23 inches.

Rise.	Tread
$5\frac{1}{2}$	12
6	11
$6\frac{1}{2}$	10
7	9
$7\frac{1}{2}$	8

The limits of the variations of steps are from 9 × 7 to 11 × 6 for ordinary purposes, and are the most useful in practice, the former measurement for ordinary and the latter for more important buildings.

Width of Stairs.—The minimum width of stairs should admit of two persons conveniently passing each other. This cannot conveniently be done under 2 feet 9 inches, but 3 feet is the more common dimension of all ordinary work of a good character.

The winders should have at least the width of the fliers on a curved line 15 inches from the centre of the newel.

Height of Straight Flights.—To prevent giddiness the number of steps will vary with the pitch of the stair, 8 feet being the maximum vertical rise without a landing or turn. Greater heights should only be reached by flat pitches, such as 11 in. × 6 in. or 12 in. × $5\frac{1}{2}$ in.

Wood for Stairs.—In ordinary practice northern pine is used for all parts of stairs, but oak and teak are used for more important work, and are better for resisting great wear.

Pitch-pine is hardly suitable, although often used for ornamental effect for all parts of stairs, but unless thoroughly seasoned it shrinks and the joints open.

Italian walnut, for its colour and figure, is sometimes

utilised for strings, balusters, newels, and handrails of stairs. Mahogany and teak are preferable for handrails, as they are durable, ornamental, and take a good polish.

Framing and Setting-out of Stairs.—The pitch and going are first determined, and a pitch-board made as shown in

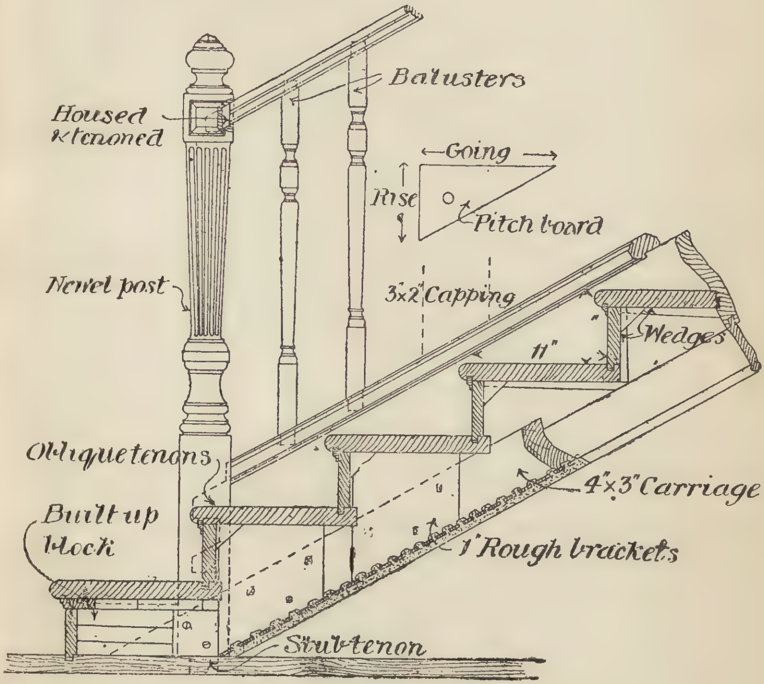


Fig. 541.

figure 541. The strings and newels are then dressed and set out by the aid of the pitch-board and plan of stairs; these are then housed, and the strings tenoned to the newels.

The risers and treads are prepared, fitted and glued;

blocked to each other they form steps, and when set are fitted into the strings. After all have been fitted together the oblique tenons of the strings are glued and dowelled to the short newel, as shown in figure 541 (the longer newels not being secured until the work is in position, owing to the difficulty of transport); the steps are wedged to the strings, which then are ready to be fixed, and when *in situ* the rough carriages are fixed beneath, as shown in figures 547 and 548, to prevent distortion of the steps when subjected to rough usage, pieces of wood termed brackets, usually 1 inch in thickness, are cut and fitted

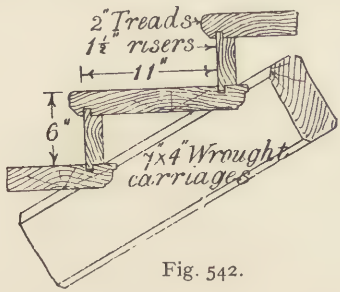


Fig. 542.

to the underside of the step and spiked to the rough carriages, and cut flush with the underside of the latter, as shown in figure 554.

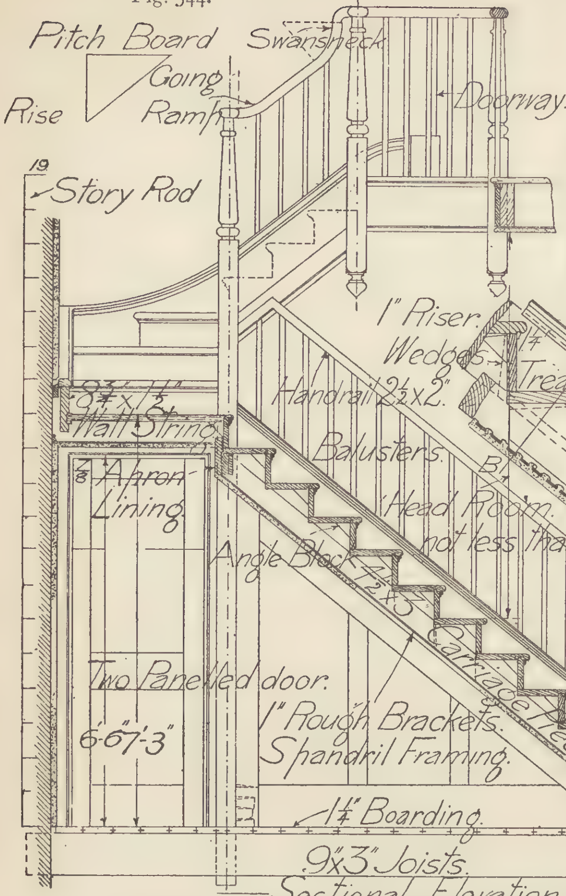
Classification.—Stairs are of two kinds:—(*a*) Newel, (*b*) well.

Under (*a*) come the straight, dog-legged, solid newel, and circular or rectangular.

Under (*b*) are included the open newel and the geometrical.

Straight stairs are useful for long narrow chambers; dog-legged for staircases the width of which is slightly more than that of two stairs; geometrical or open newel for those chambers of a greater width.

Fig. 544.



Sectional Elevation. A.A.

Scale

Fig. 547

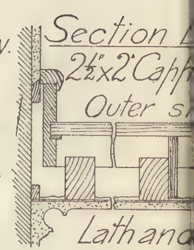


Fig. 548.

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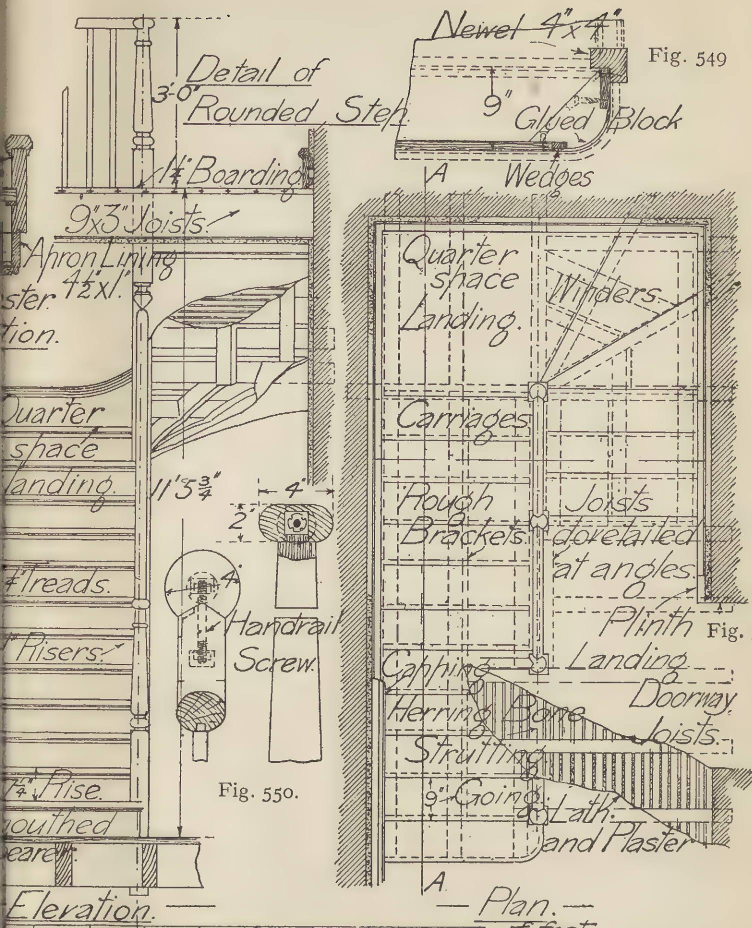


Fig. 549

Fig. 546.

Fig. 550.

Fig. 545.

—550.

[*Between pages 592 and 593.*

Open newel stairs present the best appearance and are strong.

Geometrical stairs require care and a good deal of skill in their construction; they are not so imposing as the open newel, and are comparatively weak; they were extensively used in middle-class houses of the Georgian period.

Newel Stairs.—Figures 544 to 550 show plan section, elevation, and details of steps adaptable to newel stairs, showing treads, risers, rough brackets, rough carriages, wall and outer strings, cappings, apron lining, and plaster soffit.

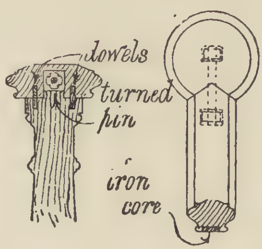


Fig. 543.

Figure 549 shows the form of construction and method of fixing a quarter-round bull-nosed step by a block glued and screwed and formed of three pieces, the grain of each piece crossing the other at an inclination, forming the fixing for the sunk and wedged riser.

Dog-legged Stairs.—Figure 537 shows the outline plan of typical dog-legged stairs, with bull-nosed step, fliers, quarter-space landing and three winders.

Figures 544 to 550 give the working drawings showing pitch-board, story-rod, handrail with ramp and swansneck, and showing accurately all the necessary details.

Open Newel.—Figure 538 is an outline plan of an open newel stairs, with a semi-crcular bull-nosed step, and the

construction is similar to the ordinary bull-nose shown in figure 549. This system is very effective when the width of each of the stairs is equal to two-sevenths that of the staircase, thus enclosing a well the width of which is three-sevenths that of the staircase. The constructional details are similar in every respect to those of the dog-legged.

Geometrical Stairs.—Figure 539 shows a plan of a type of geometrical stairs with curtail steps, wreaths about wells, quarter-space landing and winders.

Figures 551 to 558 give all the necessary drawings for such a staircase.

The string wreaths are constructed by making a centre upon which the portion of string to form the wreath, which has been already set out and sunk, is bent and temporarily fixed, face to the centre, to which upright staves with radiating joints are fitted and rubbed with glue, and on the unseen internal face of which canvas is glued to increase the rigidity and tenacity.

This when set is released from the centre and is cut to the set out marks and tongued to the grooved string as shown in figure 559. The straight as well as the curved portions of the string are then secured together by pieces of stuff arranged on the gib and cotter principle, similar to that shown in figures 867 and 868, *Elementary Course*, and known as the Counter Cramp.

Figure 557 shows such a joint; the screws lettered are those which are fixed after the wedges have been driven home.

Figure 559 gives the plan showing all the necessary lines to set out a curtail step; the block is made in three thicknesses, glued together with the grain at an angle of about 45° to each adjoining piece, to prevent any tendency to split.

The contour of the curtail follows the outline of the

Fig. 554.

Fig. 556.

Fig. 553.

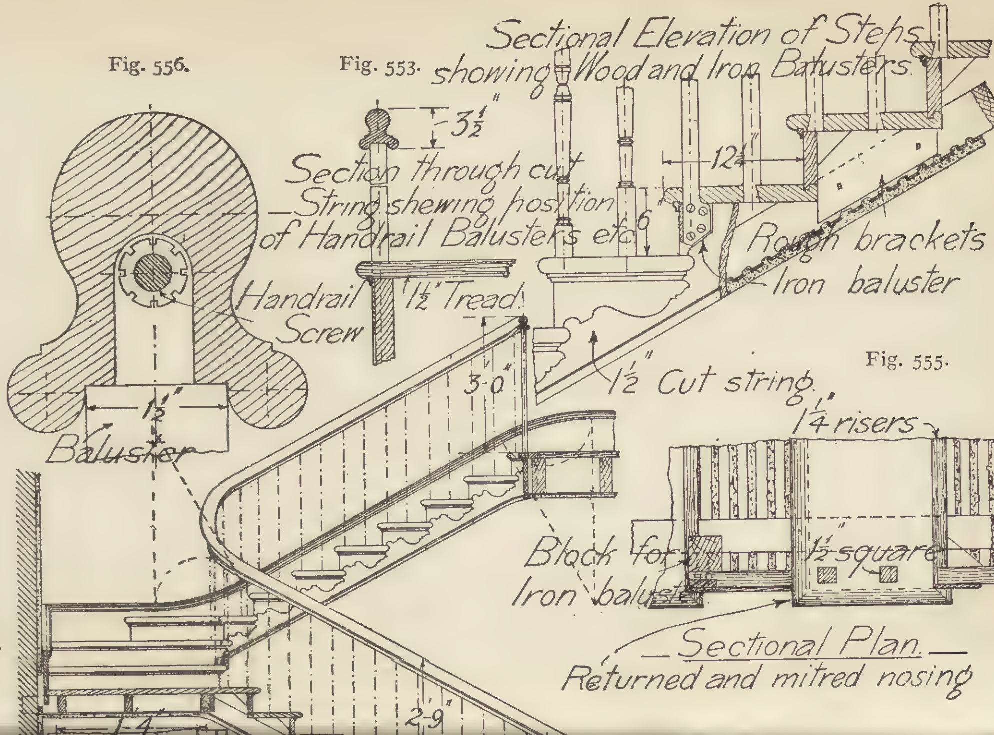


Fig. 555.

Fig. 551.

Fig. 557.

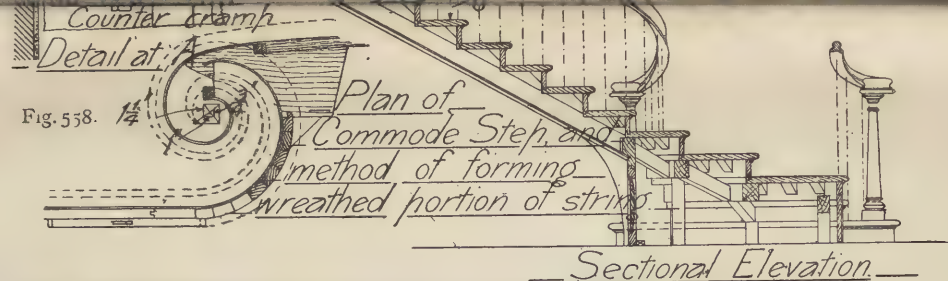
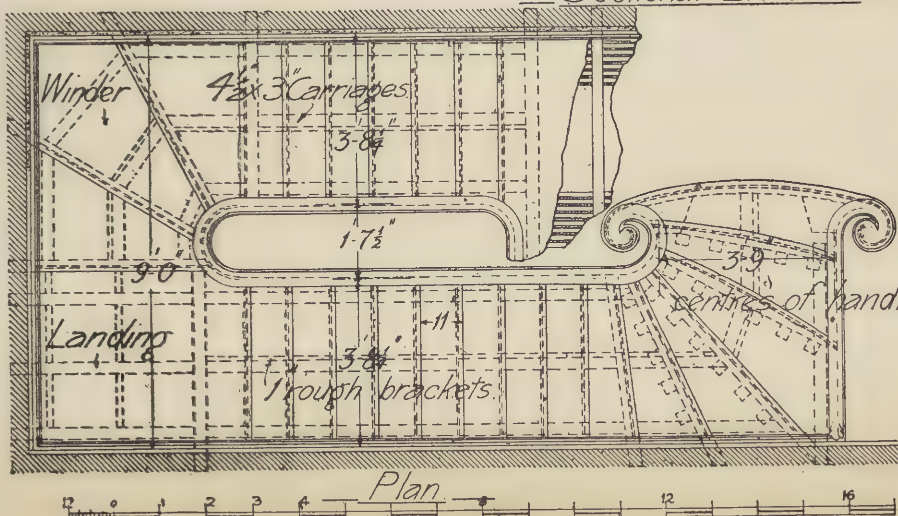


Fig. 558.

Fig. 552.



Figs. 551—558.

[Between pages 594 and 595.

scroll, both being set out from the same centres, which in this case are obtained by first drawing a right angled triangle, the perpendicular sides being one inch and $1\frac{1}{4}$ inches, the other points being obtained by drawing similar triangles, as shown in figure 559.

Figures 553 to 555 give the plan and elevation, showing the junction of risers, treads, string and straight balusters of

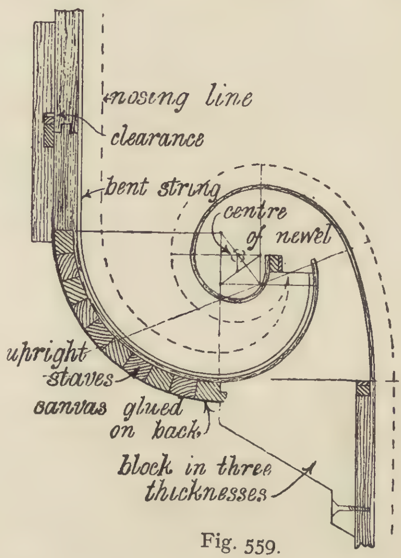


Fig. 559.

the outer cut string. The lower ends of the iron balusters are sometimes forged and screwed to the string, which has a block to strengthen it and receive the screws at that part. The thin ornamental bracket is planted on the string mitred with the riser and covering the baluster end. Bracket balusters similar to those shown in figure 232 are often fixed to the face of the string.

Handrailing.—The contour of the handrails in dog-legged stairs follows the line of the string, being ramped, mitred,

and fixed to newel caps by double-nutted screws, as shown in figure 543, or tenoned to newels, as shown in figure 541.

The handrails for open newel stairs are usually straight, and are tenoned and dowelled to newels, the heads of the latter usually being turned. Where handrails are used on the wall side they may be ramped, as shown in figure 544.

A ramp with a vertical scroll is shown in figure 560. In geometrical stairs the handrails should be constructed to present a graceful appearance, which effect is best

Fig. 560.

obtained at a minimum cost by setting out the handrails and stairs on the tangent system.

Tangent-helical-joint at Springing Point System.—The production of handrails for continuous strings is accomplished by conceiving the centre line of rails enclosed by a series of lines tangent to the curve, which should, wherever the plan is circular, be a helix if possible, and by placing the joints at the points of contact made by the tangent lines and the curves. The following drawings are necessary :—

(1) The plan with centre line of handrail and tangents, as shown in figures 566 and 576.

(2) The developments of the tangents, as shown in figures 567 and 577.

(3) The development of the face of the string on a vertical plane, as shown in figures 568 and 578.

(4) The face mould, for preparing the cylindrical surfaces of the rail, as shown in figures 569 and 579.

(5) The bevels, as shown in figures 570 and 577.

(6) The development of the falling moulds, or the cylindrical surfaces of the rail in all cases where the helical curve is departed from.

Setting out Handrails.—In setting out the work the following principles should be rigidly adhered to, and all rule of thumb methods discarded, all lines and processes should admit of geometrical proof, thus avoiding ambiguity and producing the best workmanship and scientific results in the most economical manner :—

1st. Any pair of tangents on any certain cylinder can have only one falling line. In geometrical language the falling line or curve is the intersection of the cylinder with the plane containing the tangents.

2nd. If two tangents about a circle in plan when developed form a straight line, the falling line will be a helical curve, and when developed will be a straight line.

3rd. It is desirable to have the stairs about the well-holes symmetrical ; this can be done in the case of the half-space landing, or where winders occur all round the well or in a quarter-turn.

4th. In the case of quarter-space landing and winders the developed falling line for the portion over the winders can be made straight ; for the other half the rail will be of double curvature.

5th. The plane of the joints should in every case be at right angles to the tangent lines, therefore joints should always be arranged at a point of contact of the curved line with the tangent ; in other words, the springing point as indicated in plans and elevations, figures 560 and 567, 571 and 572.

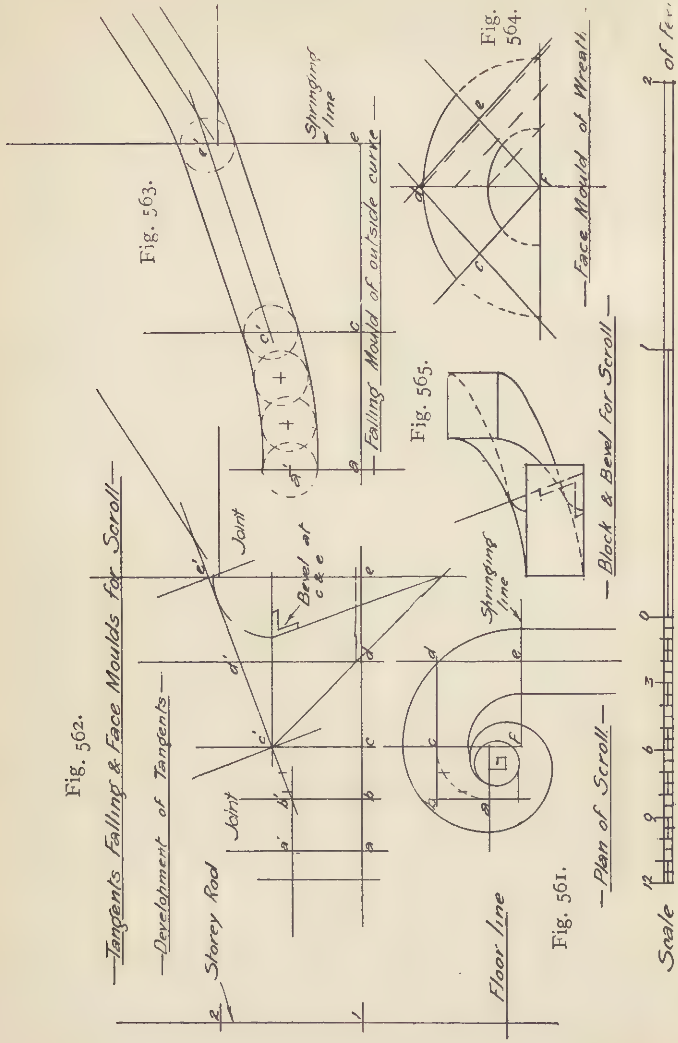


Fig. 562.
—Tangents Falling & Face Moulds for Scroll—
—Development of Tangents—
Storey Rod
Joint
Bevel at c & e
Fig. 563.
Stringing line
—Falling Mould of outside curve—
Fig. 564.
—Face Mould of Wreath—
Fig. 565.
—Block & Bevel for Scroll—
Stringing line
Floor line
Fig. 561.
—Plan of Scroll—
Scale of Feet
12 9 6 3 0 1 2

6th. All easements between straight and curved portions of the rail to be made on the rail, the centre line of which is straight in plan to avoid double curvature at any part.

There are four general types which cover all the ordinary cases met with in practice:—

1st.—The scroll.

2nd.—The wreath, about a half space landing.

3rd.—The wreath, about a half space with six winders.

4th.—The wreath, about a half turn with quarter-space landing and three winders.

1. *The Scroll.*—The method of procedure is as follows: First draw the plan of the scroll and fix the position of the tangent lines, develop the tangents and the plane containing the face of the string. In all cases the steps should be arranged with regularity and symmetry. Draw the development of the rail above the string plane, taking care in any wreath portion to arrange the developed rail as straight, in order that when it is worked to its cylindrical form it will be a true helix. It is usual to make the scroll or block half a riser higher than the ordinary part of the rail; this causes a variation in the pitch of the rail, necessitating easements at the points c and e in figures 561 and 563. Having fixed on the development of the rail the heights of the points c and d, project them across on to the development of the tangents. On the latter drawing, set out the tangent $e'\ d'\ c'$ and produce to b', at b' draw the tangent $b'\ a'$ horizontal. At a point about three inches from e' set up the centre line of the rail at the pitch of the stairs.

Prepare the face mould, from the plan draw the figure 564, F, c, d, e. The true length of the line $F\ d$ is shown on plan; the true lengths of the sides of the quadrilateral $f\ c$, $f\ e$, $d\ e$, and $d\ c$ can be obtained from the elevation of the tangents; the quadrilateral containing the springing and level lines of the face mould can then be drawn as shown

in figure 564. The face mould is in all cases a portion of a section of a hollow cylinder, and, therefore, portion of an ellipse, as the plane containing the tangents is inclined. As the two tangents *c d* and *d e* are equally inclined the face mould will be symmetrically disposed about the minor axis *f d*. The lengths of the minor axes, or level lines, can be obtained from the plan, figure 561. The major axes, the inclinations of which are always the pitch of the planes, are obtained by drawing lines from the extremities of the minor axes parallel to the tangent lines *d e* and *d c*; having the major and minor axes the ellipses may then be drawn, and the face mould will be that portion contained between the lines *f c* and *f e*, figure 564. For the preparation of the scroll block, let an elevation be drawn parallel to the tangent *b d* as shown in figure 565. The bevel for the joint can be obtained from the elevation of the tangents, figure 562. It must be particularly noted that all joints in this system are at right angles to their respective tangents, and are made before the stuff is shaped.

Bevels for Wreaths.—The bevels to be used with the face moulds represent the dihedral angle at each extremity between the vertical plane containing the tangent and the plane containing the centre line of the rail.

2. *Wreath about Half Space Landing.*—Draw the plan, as shown in figure 566, showing centre line of the wreath and face of string. Draw tangent lines *a*, *b*, *c*, *d*, *e*, enclosing the centre line of rail, set out the elevation of the tangents developed on a plane. Let the landing extend into the straight portion of the stair about three inches beyond each springing line, draw the fliers and the centre line of the rail touching the nosings, then set out the tangent from the lower to the upper nosing as shown on figure 567. As the tangents form a straight line the resulting wreath will be a helix, from these tangent lines draw the face moulds as

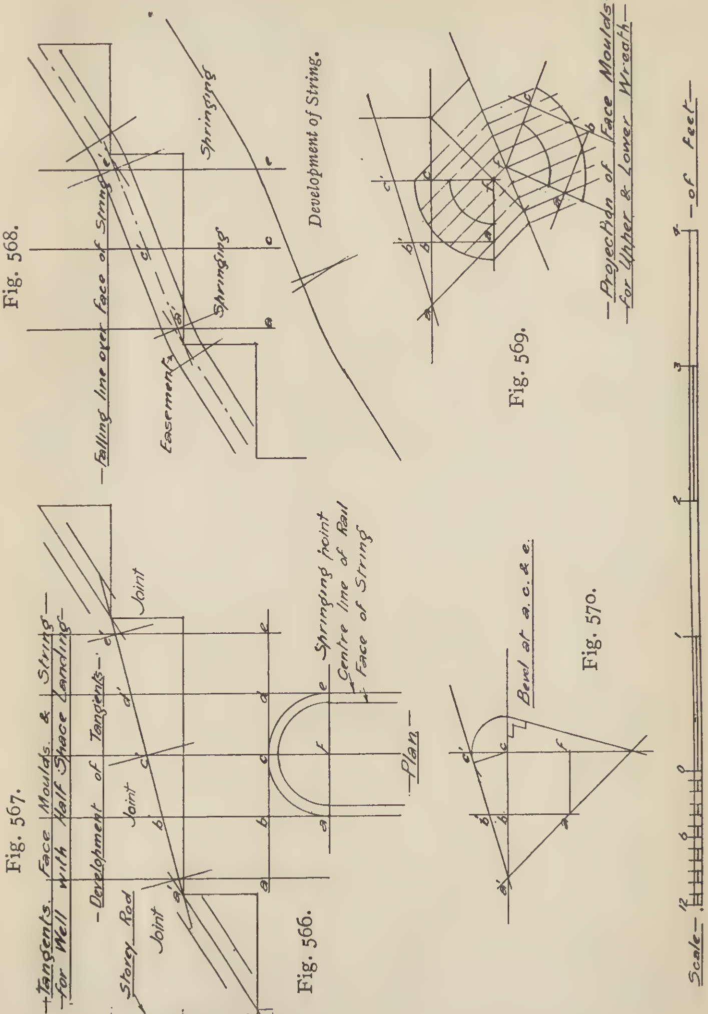


Fig. 566.

Fig. 567.

Fig. 568.

Fig. 569.

Fig. 570.

before described and shown in figure 569. As the tangents are symmetrical about the centre line *c*, one face mould will be true for the upper and lower portions of the wreath. Develop, as before described, the face of string, as shown in figure 568. The section of the rail immediately above the string is also shown, and gives the method of obtaining the easements between the wreath and the straight portions of the rail. The methods of obtaining the bevels are shown in figure 570 to prevent ambiguity.

3. *Wreath with Six Winders.*—The procedure in this example is identical with case No. 2, the winders being set out symmetrically about the centre line and projecting about three inches into the straight portion of the rail at the upper and lower springing points. Figures 571 to 575 show a plan, development of tangents, development of face of string, face mould and bevels for this example.

4. *Wreath about a Half Turn, with Quarter Space Landing and Three Winders.*—Draw the plan showing the face of the string; centre line inside and outside of rail, with the enclosing tangents *a*, *b*, *c*, *d*, and *e*, as shown in figure 576. Draw the elevation of the tangents with their developments; set out the lower steps marked 11 and 12, keeping the nosing of 12 about three inches beyond the springing point and step 16, keeping the nosing about three inches beyond tangent line *e*. Draw the elevation of the tangent *a b* horizontally, and keeping it about one inch above the level of the nosing No. 12. Draw the tangents $b' c'$, $d' e$ commencing from b' and joining the centre line of the upper portion of the rail at the nosing 16, as shown in figure 577. By this arrangement the portion of the wreath over the winders wil form a helical curve, the face mould for this may be prepared and the rail produced without the aid of a falling mould. The lower portion of the wreath will have

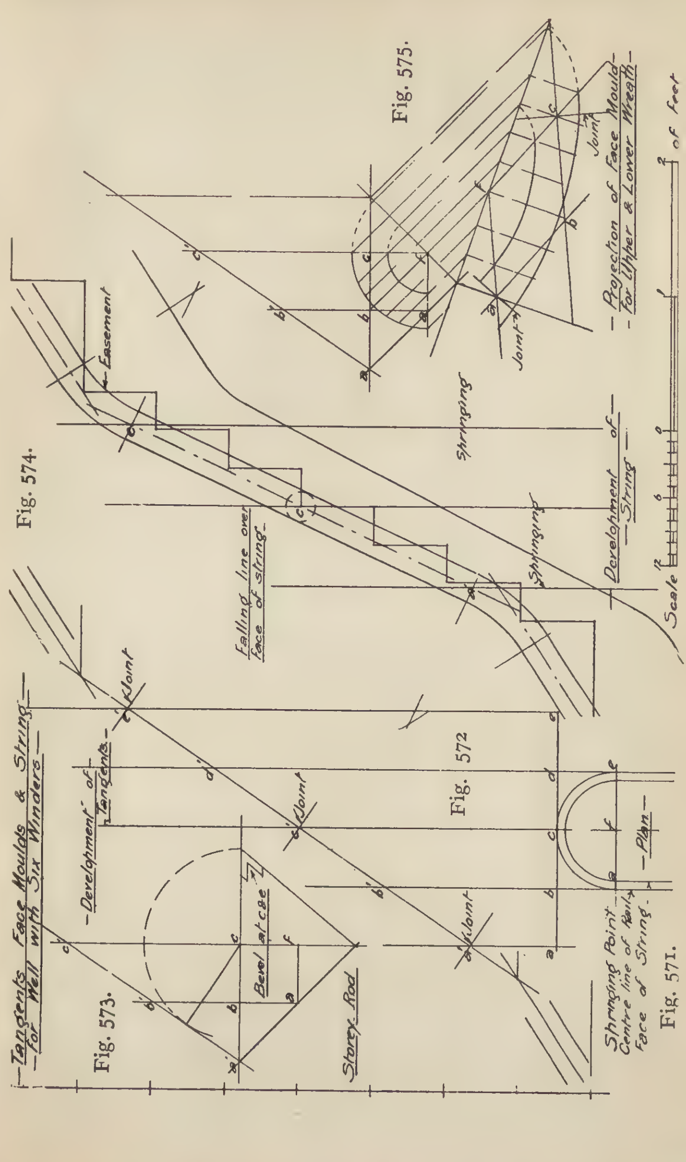


Fig. 571.

Fig. 572

Fig. 573.

Fig. 574.

Fig. 575.

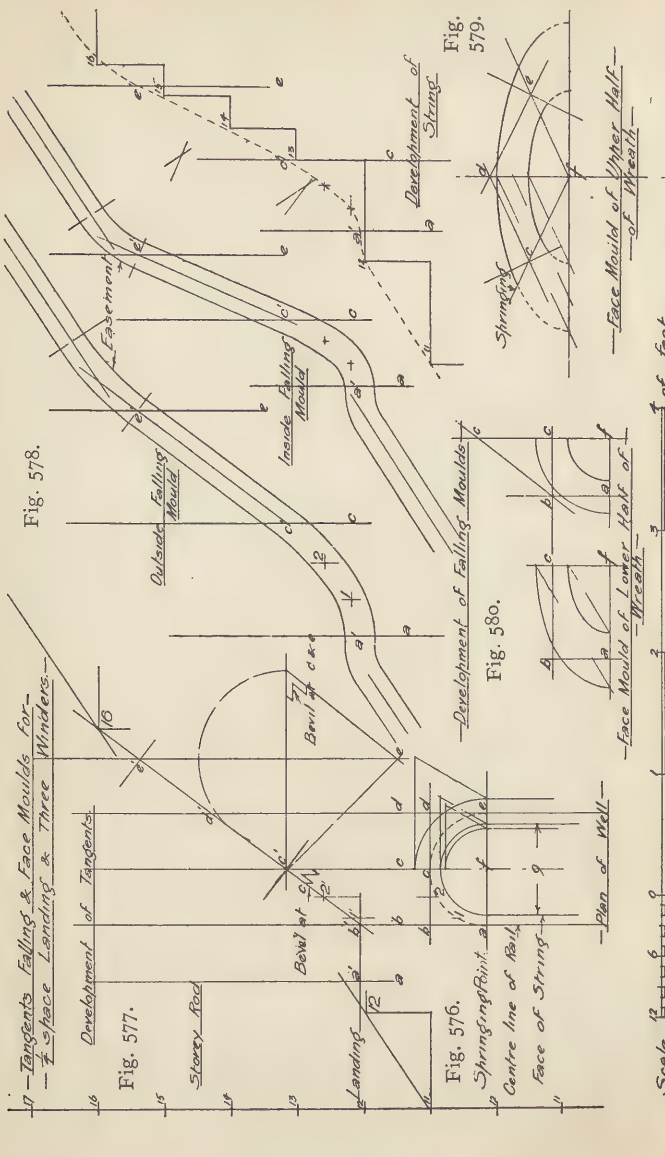


Fig. 576.
Fig. 577.
Fig. 578.
Fig. 579.
Fig. 580.

a double curve, and will require a face mould to work its cylindrical faces and two falling moulds to give to it the vertical curves. The method of preparing the face mould will be as previously described for No. 1 case. The method of producing the falling moulds is as follows: Develop the inside and the outside cylinders; the heights of the points *c* and *e* can from the developments of the tangents be projected; as shown in figure 578 the upper portion of the

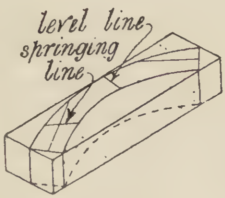


Fig. 581.

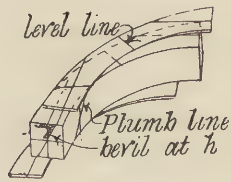


Fig. 582

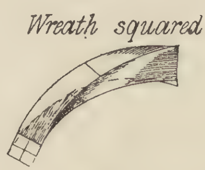


Fig. 583.

wreath can be drawn in direct, as, being a helical curve, it will show as a straight line in its development. Complete the easement for the upper portion of the wreath on the straight portion of the rail in plan. Draw the lower straight portion of the rail with its easement, as shown in figure 578. The method of connecting these two parts of the rail will be as follows: Divide the centre line of the lower portion of the rail into three equal parts, *a*—1, 1—2, 2—*c*, draw the vertical lines passing through 1—2 in the vertical parts of the rail, then obtain the heights of the points 1 and 2. The

points 1 and 2 are obtained in the plane bounded by the tangents a—b, and b—c as follows: Project the points 1 and 2 on the tangent $b' c'$, this will be the heights of the points 1 and 2, because the tangent $a' b'$ is horizontal. Project these points on to the two developments of the rail, then having four points in the lower portion of the rail the curve may be drawn, as shown in figure 578. Figures 579 and 580 show the face moulds.

The line marked level line in the figures 581 to 583 is that part at which the rail may be imagined to commence twisting in the opposite direction.

The method of setting out rail on the dressed plank is shown in figure 581 ; and of sliding the duplicated moulds to get the twist is shown in figure 582 ; and the view of the finished portion of wreath is shown in figure 583.

CHAPTER XV.

SANITATION.

Classification.—The sanitation of buildings consists in making provision, 1st, for all parts of a building to have a sufficiency of light obtained directly from the exterior; 2ndly, to be plentifully supplied with pure water; 3rdly, be well ventilated by means of constant and steady currents of fresh air; and 4thly, be provided with means for the speedy removal of offensive matters.

Lighting.—The first condition for habitable rooms is usually satisfied by complying with the provisions of the Model Bye-Laws, which are as follows:—

"Every person who shall erect a new domestic building shall construct in the wall of each storey of such building, which shall immediately front or abut on such open spaces as, in pursuance of the bye-laws in that behalf, shall be provided, in connexion with such building, a sufficient number of suitable windows in such a manner and in such a position that each of such windows shall afford effectual means of ventilation by direct communication with the external air.

"Every person who shall erect a new building shall construct in every habitable room of such building one window at the least, opening directly into the external air, and he shall cause the total area of such window, or, if there be more than one, of the several windows, to be clear of the sash frames, to be equal at the least to *one-tenth* of the floor area of such room.

"Such person shall also construct every such window so that one-half, at the least, may be opened, and so that the opening may extend in every case to the top of the window."

Provision should also be made for staircases and corridors to be efficiently lighted. A convenient position for lighting the former is from the top, but all landings should have windows wherever possible. Corridors should be lighted at the ends, and, if very long and it is convenient to do

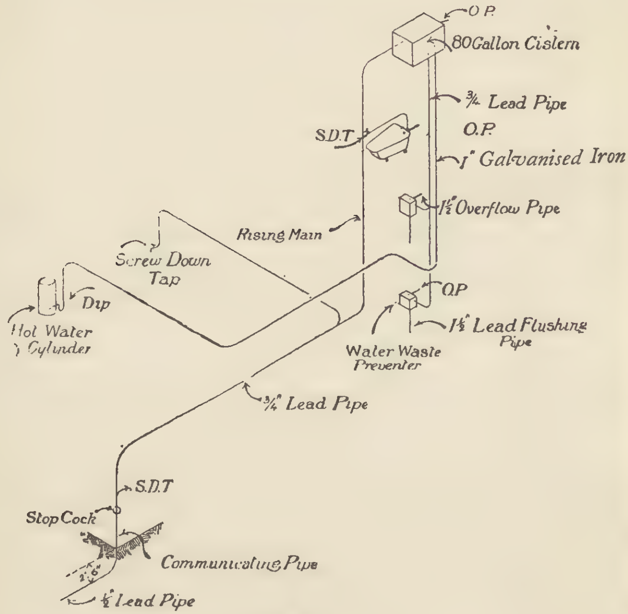


Fig. 584

so, by ceiling- or sky- lights. All windows should be capable of being opened for air currents to pass through when desired.

Water Supply.—Pipes and fittings for the storage and distribution of water for dietetic purposes should be so arranged and fixed that the water is not brought into contact with contaminating influences. In towns the water supply for drinking and culinary purposes should be drawn

from the rising main pipe, and not stored in cisterns, where, by its inherent power of attraction, the water may absorb noxious gases, or develop organisms injurious to health. Figure 584 is an isometric view, showing the disposition of the pipes and fittings for the cold water supply of a residence.

Water used for the cleansing and flushing of sanitary arrangements should not be taken directly from the main, but from a cistern in which the supply is automatically regulated by means of a ball valve.

The following table gives the weights of lead pipes as required by the London Water Companies, with the condition that every pipe shall be of the same thickness throughout its entire length :—

Internal diameter of pipe in inches.	Weight of pipe in lbs. per lineal yard.
$\frac{3}{8}$ inch	5 lbs.
$\frac{1}{2}$,,	6 ,,
$\frac{5}{8}$,,	$7\frac{1}{2}$,,
$\frac{3}{4}$,,	9 ,,
1 ,,	12 ,,
$1\frac{1}{4}$,,	16 ,,

Description of Pipe.—The water companies' regulations, based on the Metropolis Water Act, 1871, state: "Every pipe hereafter laid or fixed in the interior of any dwelling-house for the conveyance of, or in connection with, the water of the Company, must, unless with the consent of the Company, if in contact with the ground, be of lead, but may otherwise be of lead, copper, or wrought iron, at the option of the consumer."

Healthy Air.—Atmospheric air is dangerously vitiated in houses by foul gases due to the following causes:—(1) Damp sites, walls, or roofs; (2) decomposition of material used in construction, notably the timber; (3) enclosed spaces which are neither air-tight nor well ventilated, such as the spaces enclosed by hollow walls; and by (4) the overcharging of the atmosphere with carbon-dioxide caused by respiration in an ill-ventilated chamber; or

(5) by saturating the atmosphere with noxious gases from decomposing organic waste matter contained in dust-bins, privies, etc.

House Refuse and Dust Destructors.—House refuse should not be allowed to accumulate and decompose in or near

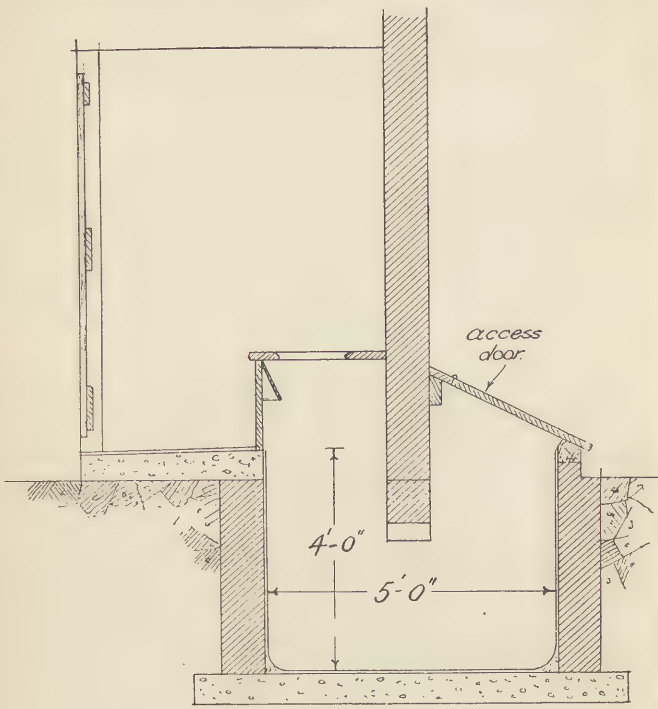


Fig. 585.

habitable dwellings; (1) in rural districts it should be speedily distributed over the land; (2) in towns fixed dust-bins should not be used, but in their place portable galvanized iron vessels with lids, and having a capacity of not more than two cubic feet, should be provided and placed

in the open air in the rear of each building, and emptied daily; but they must not be less frequently cleared than once in every week, otherwise there will be great danger of the atmosphere being seriously contaminated by the decomposition of the contents. If emptied weekly, it is usually found that it is necessary to have a content of $3\frac{1}{2}$ cubic feet in the portable vessel.

In rural districts there is little or no difficulty in disposing of the house refuse upon the land. But in London

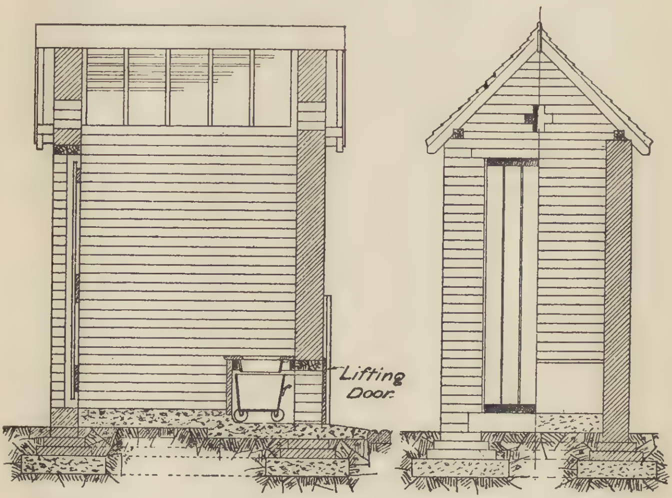


Fig. 586.

and large towns it is more economical and sanitary to reduce it to ashes by burning in large furnaces or dust destructors.

The great improvement in recent years in the design and construction of dust destructors in England renders it possible to reduce large quantities of refuse matter with economy, and provided they are erected in non-residential areas, and away from public buildings such as schools, churches, &c., need not be any more objectionable than the

output of an ordinary factory chimney, and up to the present this is the only satisfactory method from the hygienic standpoint for the disposal of house refuse, offal, &c., with their attendant microbes.

Closets.—Classification.—There are three kinds of closets: (1) the privy, (2) the earth closet, and (3) the water closet.

Privies.—The privy is simply an enclosure, as shown in figure 585, with a pit beneath the seat, constructed in such a manner that it may be easily cleaned out. To comply with the Model Bye-Laws, a privy must be 6 feet at least away from any dwellings or business structures, and cleansed every week. But in towns, or anywhere in close proximity to buildings, a privy is a nuisance and dangerous to health, and therefore this form of closet should not be used.

Figure 586 shows an arrangement with a movable receptacle, which can be emptied as frequently as it may be desired.

Earth Closets.—An earth closet is shown by figure 587, and consists of an enclosure, built in a detached outbuilding, or abutting against the dead wall of a dwelling. The entrance should be outside, and there should not be any communication with the atmosphere inside the house. These closets should be provided either with an automatic acting arrangement, or with the means of adding by hand sufficient dried ashes, dried and powdered clay, dry earth, loam, or sawdust, to cover the deposit at each usage of the closet. Sand and gravel are of little value for deodorizing the deposit or absorbing liquid fæces.

Earth closets are frequently fixed in country houses, schools, cottage hospitals, and similar places. But the rooms in which they are fixed should be well ventilated, the walls next to adjoining rooms made perfectly air-tight, and the entrances should be from passages or landings and not from any living rooms.

Earth closets are fitted with movable receptacles beneath the seats, and should be cleared out daily, or at least once in every three days.

In some towns, such as Nottingham and Manchester, pails lined with absorbent material were placed beneath the seats until these last few years; but in these towns, and many others, the earth closet system is now being superseded by the water carriage system.

In villages and cottages the privies are sometimes con-

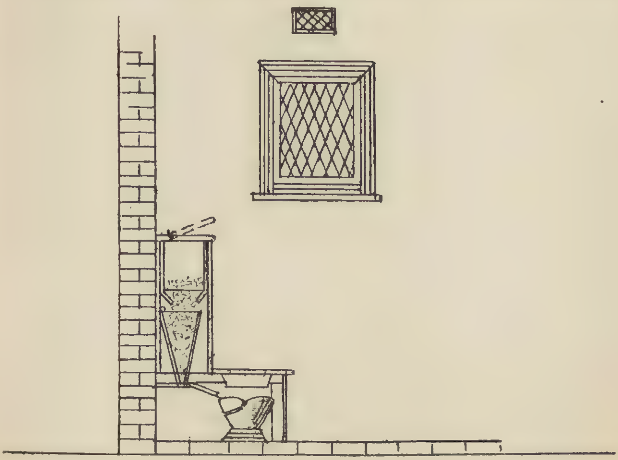


Fig. 587.

verted to the earth closet principle by using them as dust shoots or ash pits.

The pail system for small towns is convenient, but for large towns the water carriage system is less expensive, cleaner, and more effective.

Water Closets.—A water closet consists of a trapped bowl, or basin, which receives the fæcal matter, and which matter is washed away, by the use of water, into the drains and sewers.

Drainage of Surface Water and Sewage Matter.—The surface water and sewage matter are conveyed away with either of two systems of drains, one for surface water and one for sewage matter, or both surface water and sewage matter are transported by one system.

The former method is often carried out in districts where the sewage is chemically or bacterially treated to save the expense of treating the surface water; this is not advisable: advantage should be taken of the surface water in times of heavy downpours to scour the drains and sewers, and thus automatically to ensure that at least a periodical cleansing and water flushing of the drains is effected, and in addition to this the method of having two systems of drains in each dwelling house is an unnecessary and additional expense, and risk to health from possible defects. The latter method, therefore, only will be treated of here.

Water Carriage System.—In a town where the water carriage system for removing fæcal matters is adopted, an elaborate system of drains and sewers is necessary. For the houses to be healthy there must be:—

(*a*) Complete disconnection of the house drains from the sewers or cesspools by the use of disconnecting traps.

(*b*) Disconnection of rain, bath waste, or other waste water pipes by causing them to discharge in the open air over or into properly constructed stoneware gully traps.

(*c*) Ventilating the drains, sewers, and foul water pipes by inducing currents of air to pass through and so flush every part of the interior of the drains and pipes. To obtain the maximum of efficiency there should be as few dead-ends as possible, and where these cannot be dispensed with, the drains and pipes should be made as short as possible.

(*d*) Constructing the means for conveying away all liquid waste in such a manner that every part liable to be fouled will, by ordinary usage, be as nearly as possible self-cleansing.

The drains and pipes should also be periodically flushed with clean water, the object being to rapidly transport all offensive decomposing matter to the sewers.

All drains, pipes, and other channels and conveniences should be made as small as possible, and of materials which are non-absorptive, smooth, durable, and proof against the

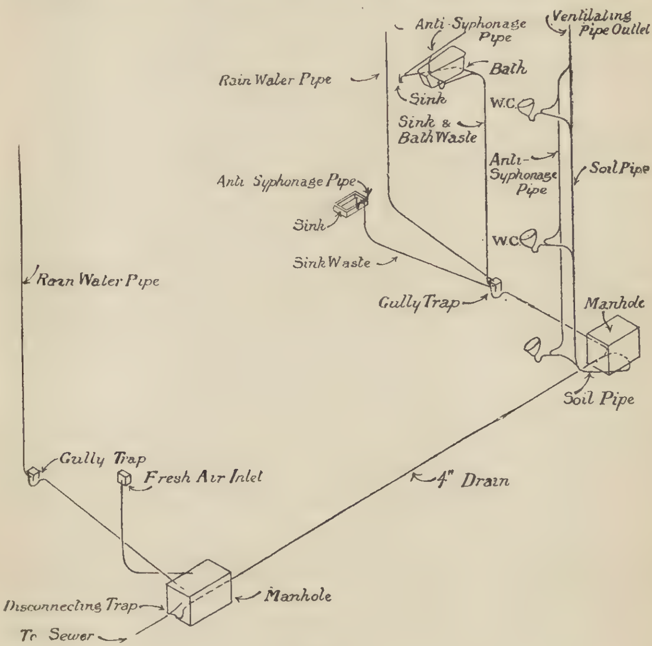


Fig. 588.

escape of drain air. All drains should be periodically inspected and cleansed. When laid underground the drains should be enclosed in cement concrete to prevent fracture either by settlement or crushing of the earth or surroundings.

Figure 588 is an isometric view, showing a system of drainage for a small residence, which will satisfy the requirements of the London County Council, as given on pages

630 to 643, and which illustrates the foregoing subdivisions of the subject.

Materials for Drains.—All drain pipes, channels, bends and other appliances should be made as small as possible to be efficient, permitting of the maximum sphere having a clear way throughout its entire length, and the appliances should be of materials which are non-absorbent, smooth, durable and proof against the escape of drain air; and the necessary joints and connections must be easily made, water-tight, proof against vibrations caused by mechanically driven vehicles, and durable.

Glazed stoneware and cast iron treated with a preservative solution are the two materials that most economically satisfy these requirements. The lengths of glazed stoneware are not usually of more than two feet, therefore necessitating a joint in every two feet of its length; gasket and neat Portland cement are the jointing materials.

Cast iron pipes are made in lengths of nine feet, thereby in long lengths of drains reducing the number of joints; gasket and metallic lead are the jointing materials.

Glazed stoneware pipes with Portland cement jointing is felt to be unsatisfactory for a number of years, owing to the unreliability of the Portland cement jointing, from its inherent defect of appreciable contraction and expansion, together with the damage from earth tremors. Cast iron pipes properly treated with metallic lead jointing is much more reliable, and the resistance to earth tremors caused by Nature or by mechanically driven vehicles is much more satisfactory, and, therefore, in towns and under buildings should now invariably be used, even though the initial cost may be twice as much.

Disconnection of House Drains from Sewer.—The position for disconnecting the house drain from the sewer by means of a manhole and disconnecting trap is shown in figure 588.

Disconnection of Waste Pipes from Soil Drains.—The disconnection of bath, rain-water, and sink waste pipes from sewage drains by means of gully traps is shown in figure 588.

Figure 591 shows a cast iron rain water shoe to empty into a trap similar to that shown in figure 589.

Ventilation.—Ventilation of the drains is shown in figure 588. The general form of the combination of air-inlet pipe, drain, and upcast ventilator pipe can be compared to the letter J.

The air-inlet pipe is fixed at the lower end of the drain, and is provided with an open grating or with a mica flap valve, which closes with any back pressure, when it is desirable to prevent any air escaping from the drains. The direction of the air current is from the lower to the higher end of the drain. The air in the longer air pipe, which is fixed at the higher end of the drain, is forced up by the heavier column of air which passes into the inlet pipe. The difference in weight of the two columns of air is so small that it is often counteracted by the sun heating and rarefying the air in the inlet pipe. A gust of wind blowing down the ventilating outlet pipe, or the continual flow of waste water from the fittings (which are usually at the back of the house) towards the sewer, will retard, drive back, or reverse the air current. This leads to the suggestion that in some cases it is advisable to so arrange the system of ventilation that the longer upcast pipe should be at the lower end of the drain, and the shorter inlet pipe at the higher end of the drain, and thus utilise the flow of sewage to accelerate instead of retarding the air current.

Anti-Siphonage Pipes.—To prevent the water in traps being forced out by the creation of a vacuum on the drain side of the traps by the flow of waste water down the drains, and which forces or draws the air in the pipes with it, all traps inside buildings should be provided with special

air supply pipes, as shown in figures 588 and 600. Such pipes provide for a continuous current of air to pass through, and ventilate, the pipes and drains when the sanitary fittings are not being used, and also to keep the air pressures equal on both sides of the water seal of the traps when the fittings are being used, and thus prevent the traps being unsealed by siphonage.

Manholes or Inspection Chambers.—Inspection chambers, or manholes, should be constructed at the back and the front of the house respectively for collecting branch drains into the main drain, and also for access to the main and branch drains for examination and cleansing, or for removing obstructions.

The chambers are built with brick-in-cement walls on concrete foundations, and made water-tight by rendering them inside with Portland cement and clean, sharp, washed sand. The minimum internal dimensions should be 3 feet × 2 feet 3 inches—a common size is 3 feet 6 inches × 2 feet 6 inches—and with a depth according to the depth of the drain. Figure 597 is a section of a manhole and disconnecting trap.

The manholes should be provided with air-tight covers, and in some cases should be ventilated by means of separate pipes, the openings of which should be clear of all doors, windows and other openings into the house.

Figures 589 and 590 show the construction of a manhole arranged to receive cast iron pipes and fittings.

House Drains.—In a terrace house the drain should be laid straight under the house, as shown in figure 588, so that it can be easily cleansed when required. In all detached and semi-detached houses the drains should be laid outside the houses. All drains should be laid to such falls and gradients, and be of such sizes, as to be as nearly as possible self-cleansing by usage.

All pipes above the ground should be of lead or cast iron. The drains below the ground should be of either

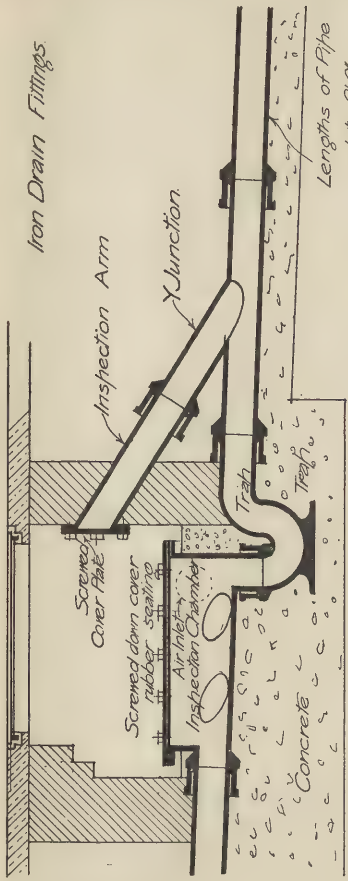


Fig. 589.

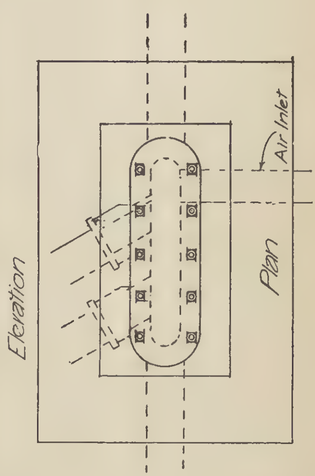


Fig 590.

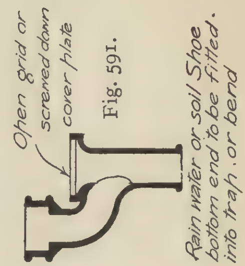


Fig. 591.

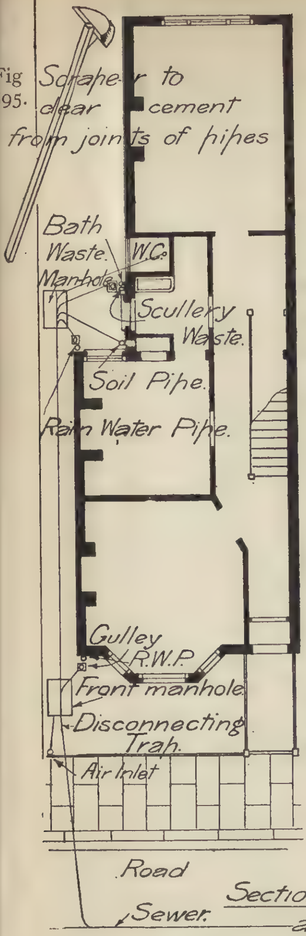
glazed socketed stoneware pipes, with cemented joints, or of cast-iron pipes, heavy water main strength, protected from rusting by the Bower-Barff process, or by coating

with Dr. Angus Smith's solution. The iron pipes should have spigot and socket joints, run with molten lead and well caulked. Where large bodies of hot water pass through iron drains they should be fitted with expansion joints as may be necessary.

Typical Drainage of a Small House.—The sewage and refuse fluid matter of domestic buildings is conveyed from water-closets, baths, sinks, etc., by means of a pipe to a cesspool or to a sewer. It is desirable to remove this matter as quickly as possible, before putrefaction takes place, and in such a manner that all objectionable odours are reduced to a minimum and so that any adjacent soil is not contaminated. Impervious stoneware, or cast iron, pipes, and good water-sealed traps are used. It is desirable that all runs of pipes should be laid straight and an inspection chamber constructed at each horizontal angle or bend to permit of easy access in case of any stoppage of the drain. The various branch drains of the sanitary system of a building should as far as possible be collected at a manhole, as shown in figure 592, and not joined to any other part of the underground system. Between the house drains and the sewer, or the cesspool, into which the drain discharges there should be a disconnecting trap, as shown in figure 597, with an effective water seal to keep the house drains free from the sewer gases. All soil pipes should be taken to drains leading direct to a manhole without any intervening traps, and their upper ends should be continued above the highest window in the house, in order that they may serve as ventilators to the drains on the house side of the disconnecting traps. All waste pipes should discharge over or into open trapped gullies in order that all such pipes may be flushed with air other than that from the drain. The laying of the drains, if of stoneware, is usually executed by the bricklayer, if of iron by the plumber. The

Fig. 592.

Fig. 595.



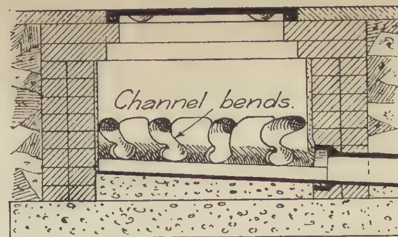


Fig. 593.

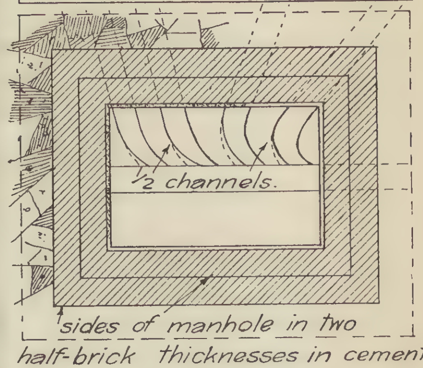


Fig. 594.

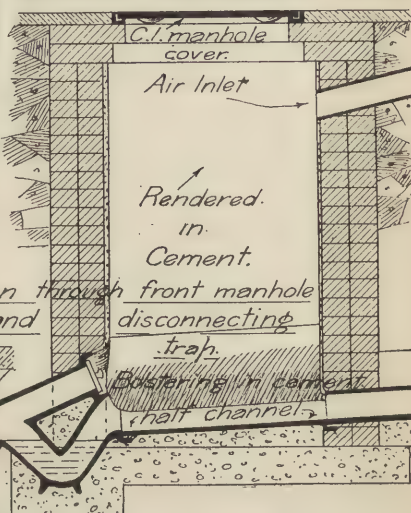
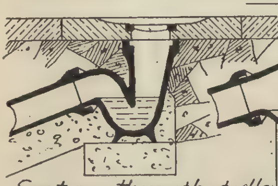
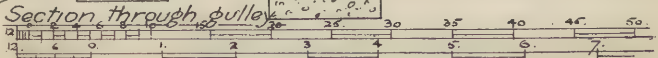


Fig. 597.

Fig. 596.





Figs. 592—597.

following would be the method adopted for a small terrace house, as shown on plan, figure 592. All other systems would be laid on similar principles, but modified to comply with any peculiar conditions.

In the case of a terrace house, the drains should be laid after the building has been erected and the ground has had time to settle.

The line of drains should be set out, the trenches cut to the true gradients, and the earth for the manholes removed; the bottoms of the trenches and the manholes are then covered with 6 inches of good concrete. The disconnecting trap should then be embedded in concrete in the lower manhole and connected with a drain leading to the sewage system. The invert channels in the lower manhole should then be bedded, and the straight portion of pipe between the two manholes laid and connected with the channels in the respective manholes. The various branch channel connections are then made, and drains laid to receive the waste water from sinks, baths, and rain water pipes through a gully trap. Such trap disconnects the drain from the outer air. Branch drains connected with soil pipes are not trapped, but the soil pipe is continued upwards as before stated to act as a vent. The manholes are then built, the walls of which are 9 inches thick and built in two separate half-brick thicknesses in cement mortar to render them less likely to leak. By having no "through" joints, excepting those for bedding the bricks, the manholes are not so likely to leak when a water test is applied. The spaces between the channels and walls are benched to a height of at least 6 inches and rendered in cement with a trowelled surface. The sides of the manhole should also be rendered in cement. After the cement has thoroughly set the drains should be tested, and, if found to be satisfactory, they should be backed up with concrete to half their height; or, if the pipes are laid under a house, they should be completely enveloped

in concrete all round the pipe for a thickness of six inches. The ground may then be filled in and lightly punned.

Many stoneware pipes are slightly curved in their length. Any pipes deviating from straightness should be so arranged as to lie in a horizontal plane, and thus avoid an irregular gradient in the invert of the drain.

The pipes are usually jointed in neat cement, which should be properly cooled, before wetting, but not "killed," or further mixed up after the initial setting has commenced, and then used. Before bedding the pipe, the socket of the last laid pipe should have a layer of cement bedded in it; the spigot end of the next pipe is then inserted, and care taken to pack it perfectly concentric with the preceding pipe. Neat cement should then be tucked in and pressed home in the socket with a piece of wood cut for that purpose, and thus ensure the joint being quite solid. The joint is then flushed up with cement. On inserting the pipe a large amount of the cement first bedded will be squeezed into the interior of the pipe; this surplus cement should be carefully scraped out, each time a joint is made, with the tool shown in figure 595, to prevent any projections on the inside of the pipe.

A better method of procedure, where straight lengths of drains occur as between two manholes, is as follows:—On the prepared bed of concrete lay all the pipes in each length or run and with a crowbar or prize, force all the spigot ends of the pipes into the sockets and hard up against the socket shoulders. Then commence at the lower end and bed the first pipe on the concrete, then lay the second pipe and ensure that it is concentric with the first pipe by packing it at the side with concrete. In a similar manner centre and bed all the remainder of the pipes. Ample clearance about the pipes should be left for the making of the cement joints. Then return to the lower end and commence to make the joints, using only cement. Care should

be taken to force the cement well into the joints ; ram it in with a wood tool specially made for this purpose. Finally, flush the joint level with the face of the socket. Most workmen leave an external fillet of cement, but this is unnecessary. The advantage of this method is that the joints can be made without causing the slightest movements in the pipes. After testing the pipes they are enclosed with concrete, as prescribed by the Bye-laws.

Flushing Cisterns.—Flushing cisterns should be fixed over every water closet and slop sink to cleanse them after being used. The urinals and drains of public buildings, workshops, and large houses are usually flushed by cisterns which act automatically at regulated intervals of time. The cisterns are fitted with annular siphons, such as Mr. Rogers Field's, as shown in figure 598. The siphon consists of an inner leg, the higher end of which is in a reservoir tank, and the lower end in a small under-chamber, the latter being constructed so as to retain enough water to cover the lower end of the pipe.

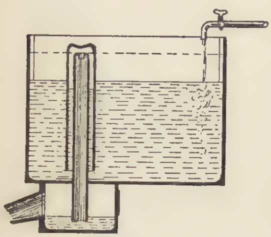


Fig. 598.

The inner leg is covered by an outer pipe, which has a closed top and an open bottom end. This pipe forms a cap over the inner leg, and leaves an annular space through which the water can rise and flow into the top end of the inner leg. The water supply is regulated by a tap arranged to flow either quickly or gently into the tank as may be desired. When the tank has filled so that the water is an inch or two above the cap of the siphon, the attained head is sufficient to so compress the air inside the siphon as to force away the water in the bottom of the inner leg. As soon as the water is forced away the air escapes, and the

inner leg is quickly filled with water, which flows away with a good cleansing force into the drains. When the tank has been emptied it slowly refills, and the whole of the actions are repeated.

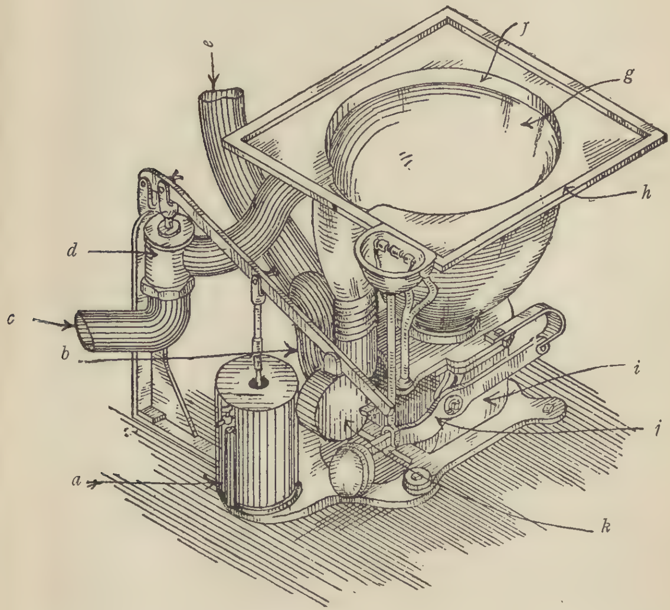


Fig. 599.

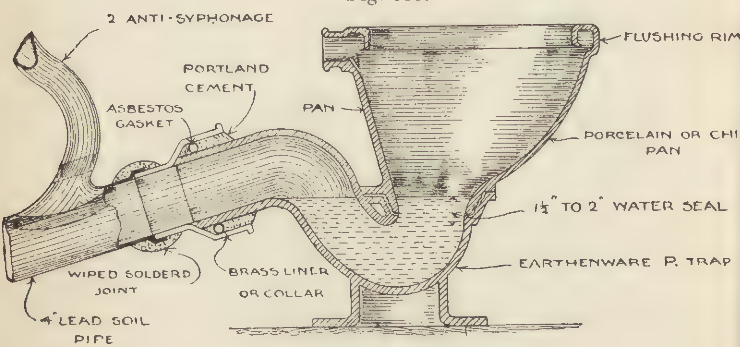
a Air cylinder to regulate flush.
b Overflow trap.
c Service pipe.
d Supply valve.
e Vent pipe to valve box.
f Flushing rim.
g Earthenware pan.
h Table top.
i Valve box.
j Lever for opening and closing basin valve.
k Cast iron weight for shutting supply valve.

This appliance has also been used for collecting driblets of rain or waste water, and storing it until the tank was

sufficiently filled as to discharge automatically into the drains. By this arrangement the drains are kept much cleaner than they would be if the small quantities of waste water simply dribbled into them.

Water Closets.—There are many kinds of water closets, those of the valve and wash-down forms being usually considered the best. All closet apparatus should conform to the following conditions: (1) They should be trapped to prevent the escape of air from either soil pipes or drains;

Fig. 600.



WASH-DOWN CLOSET.

(2) the basin should have a small surface to be fouled, and should contain a body of water to receive excreta; (3) the basins should be made of smooth and impervious material; (4) the appliance should be noiseless in action; (5) should possess sufficient strength to resist breakage; (6) the basin should have a flushing rim and be so designed as to utilise the flush of water in the most efficient manner; (7) and for general use the whole must be reasonable in cost. Valve closets are preferred for best use in mansions and high-class hotels; but for servants' use, cottage property, public conveniences, hospitals, and infirmaries, the wash-

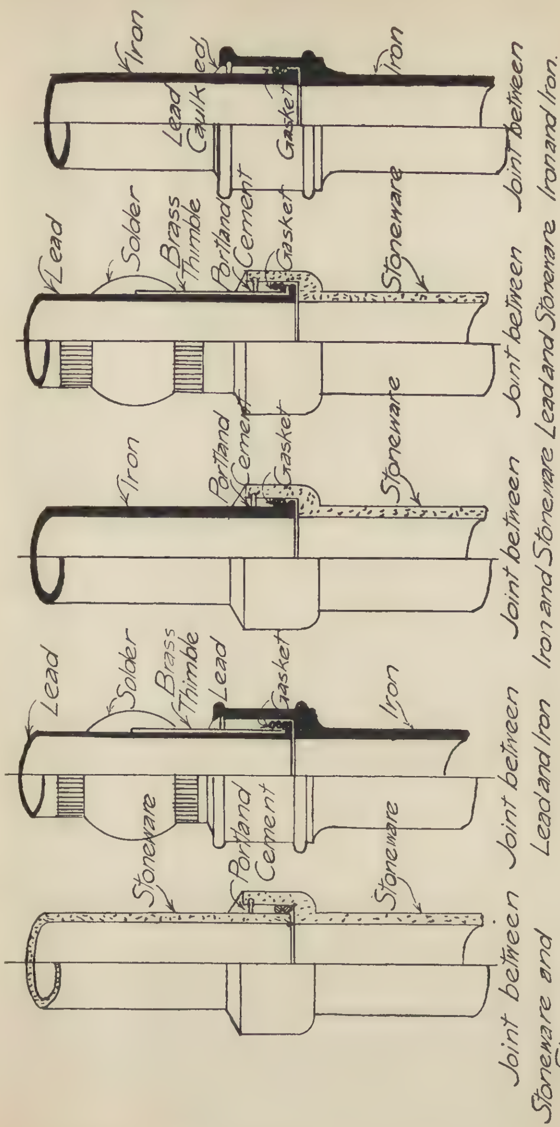


Fig. 601. Fig. 602. Fig. 603. Fig. 604. Fig. 605.

down closets are the most suitable. Figure 599 illustrates a valve closet, and figure 600 shows a type of the wash-down variety.

Improved wash-down closets are now being used with automatic discharging action, which removes the contents of the pan and trap by siphonage. After the contents of the trap and basin have been siphoned out, the trap is resealed with water by an after-flush arrangement.

W.C. Rooms.—Rooms containing water closets should be well ventilated by openings through the external walls, and the walls and floors should be so constructed as to prevent any local smells passing into the house.

Waste Pipes.—All sanitary appliances when fixed inside houses should have their waste pipes trapped immediately under the fittings, and the traps should be provided with screw caps for cleansing purposes.

Joints of Pipes.—The joint of a stoneware to stoneware pipe is made by rings of gasket pressed well against the shoulder of the socket, and the latter filled up with a ring of Portland cement as shown in figure 601.

Figure 603 shows the connection of an iron with a stoneware drain. The joint is made by gasket pressed in the socket against the spigot and a ring of Portland cement filling up the socket.

Figure 604 shows lead with a stoneware drain. The joint is made by a brass thimble with a wiped soldered joint to the lead, the lead pipe and brass thimble are both flanged as shown, gasket and Portland cement making the connection as before.

Figure 602 shows a lead with an iron drain. In this case the jointing materials of the joint differs from that previously shown by being of gasket and metallic lead well caulked.

Figure 605 shows the connection of iron to iron drain, the joint being made by gasket pressed against the spigot end of the pipe and the socket filled up with a ring of metallic lead well caulked.

Drain Testing.—There are three methods of testing the soundness of drains and fittings—viz., by (1) essences or volatile oils, (2) smoke, (3) hydraulic pressure, (4) air pressure.

1. Defects may be discovered by carefully pouring volatile oil, such as strong essence of peppermint, followed by hot water, down the highest part of the drainage system. If the odour of the oil escapes, the existence of a defect is proved. This test, however, is not reliable, as a defect may not be discovered by its application.

2. The second test consists in charging the drains with smoke by means of a smoke rocket or a smoke machine. This test can be applied through the fresh-air inlet to the drains, or through the ventilating pipe, or through a gully trap from which the water has been removed. An escape of smoke at any part would indicate a defect.

3. The hydraulic pressure test consists in stopping up the drain where it enters the disconnecting chamber by means of an inflated india-rubber bag, or by an india-rubber plug, and then filling the whole of the drainage system with water until it rises to the level of a surface gully or another manhole. If after a time, say half an hour, the water is found to subside, this would denote a leakage. This test is the only reliable one for drains, and is usually applied to drains when laid underground. For the vertical parts of a drainage system, such as the soil pipes, etc., the smoke tests, the pressure of which is only equal to about $\frac{1}{2}$ inch of water, is used and considered sufficient. All pipes should be subjected to the hydraulic and smoke test before being covered in and on completion of the works.

4. The air pressure test as applied to drains consists of plugging the soil pipes, or drain ventilating drains if any, then examining if all manhole covers are properly fitted and all traps are properly sealed with water. Air is then forced into the drains by means of a pump similar to a large size bicycle pump. A glass siphon pressure gauge filled with water is necessary to show the air pressure exerted in the drains. Under ordinary conditions an air pressure of 1·5 inches can be exerted. If a test under a greater pressure than 1·5 inches is desired it becomes necessary to plug all the gully and water closet traps in addition to the main drain trap in the disconnecting manhole. The siphon pressure gauge should be of a depth in proportion to the air pressure to be resisted.

The following are the Bye-Laws of the London County Council with respect to drains, water closets, and earth closets. These bye-laws must be complied with in London, and may be followed with advantage elsewhere :—

Water closets and earth closets.

1. Every person who shall hereafter construct a water closet or earth closet in connection with a building, shall construct such water closet or earth closet in such a position that, in the case of a water closet, one of its sides at the least shall be an external wall, and in the case of an earth closet two of its sides at the least shall be external walls, which external wall or walls shall abut immediately upon the street, or upon a yard, or garden, or open space of not less than one hundred square feet of superficial area, measured horizontally at a point below the level of the floor of such closet. He shall not construct any such water closet so that it is approached directly from any room used for the purpose of human habitation, or used for the manufacture, preparation, or storage of food for man, or used as a factory, workshop, or workplace, nor shall he construct any earth closet so that it can be entered otherwise than from the external air.

He shall construct such water closet so that on any side on which it would abut on a room intended for human habitation, or used for the manufacture, preparation, or storage of food for man, or used as a factory, workshop, or workplace, it shall be enclosed by a solid wall or partition of brick or other materials, extending the entire height from the floor to the ceiling.

He shall provide any such water closet that is approached from the external air with a floor of hard, smooth impervious material, having a fall to the door of such water closet of half an inch to the foot.

He shall provide such water closet with proper doors and fastenings.

Provided always that this bye-law shall not apply to any water closet constructed below the surface of the ground, and approached directly from an area or other open space available for purposes of ventilation, measuring at least forty superficial feet in extent, and having a distance across of not less than five feet, and not covered in otherwise than by a grating or railing.

2. Every person who shall construct a water closet in connection with a building, whether the situation of such water closet be or be not within or partly within such building, and every person who shall construct an earth closet in connection with a building, shall construct in one of the walls of such water closet or earth closet which shall abut upon the public way, yard, garden, or open space, as provided by the preceding bye-law, a window of such dimensions, that an area of not less than two square feet, which may be the whole or part of such window, shall open directly into the external air. Water closets.

He shall, in addition to such window, cause such water closet or earth closet to be provided with adequate means of constant ventilation by at least one air-brick built in an external wall of such water closet or earth closet, or by an air-shaft, or by some other effectual method or appliance.

3. Every person who shall construct a water closet in connection with a building, shall furnish such water closet with a cistern of adequate capacity for the purpose of flushing, which shall be separate and distinct from any cistern used for drinking purposes, and shall be so constructed, fitted, and placed as to admit of the supply of water for use in such water closet so that there shall not be any direct connection between any service pipe upon the premises and any part of the apparatus of such water closet other than such flushing cistern.

Provided always that the foregoing requirement shall be deemed to be complied with in any case where the apparatus of a water closet is connected for the purpose of flushing with a cistern of adequate capacity, which is used solely for flushing water closets or urinals.

He shall construct or fix the pipe and union connecting such flushing cistern with the pan, basin, or other receptacle with which such water closet may be provided, so that such pipe and union shall

not in any part have an internal diameter of less than one inch and a quarter.

He shall furnish such water closet with a suitable apparatus for the effectual application of water to any pan, basin or other receptacle with which such apparatus may be connected and used, and for the effectual flushing and cleansing of such pan, basin, or other receptacle, and for the prompt and effectual removal therefrom, and from the trap connected therewith of any solid or liquid filth which may from time to time be deposited therein.

He shall furnish such water closet with a pan, basin, or other suitable receptacle, of non-absorbent material, and of such shape, of such capacity, and of such mode of construction as to receive and contain a sufficient quantity of water, and to allow all filth which may from time to time be deposited in such pan, basin, or receptacle, to fall free of the sides thereof and directly into the water received and contained in such pan, basin, or receptacle.

He shall not construct or fix under such pan, basin, or receptacle, any "container" or other similar fitting.

He shall construct or fix immediately beneath or in connection with such pan, basin, or other suitable receptacle, an efficient syphon trap, so constructed that it shall at all times maintain a sufficient water seal between such pan, basin, or other suitable receptacle, and any drain or soil pipe in connection therewith. He shall not construct or fix in or in connection with the water closet apparatus any D trap or other similar trap.

Water closets.

5. A person who shall newly fit or fix any apparatus in connection with any existing water closet shall, as regards such apparatus and its connection with any soil pipe or drain, comply with such of the requirements of the foregoing bye-laws as would be applicable to the apparatus so fitted or fixed if the water closet were being newly constructed.

Earth closets.

6. Every person who shall construct an earth closet in connection with a building shall furnish such earth closet with a reservoir or receptacle, of suitable construction and of adequate capacity, for dry earth, and he shall construct and fix such reservoir or receptacle in such a manner and in such a position as to admit of ready access to such reservoir or receptacle for the purpose of depositing therein the necessary supply of dry earth.

He shall construct or fix in connection with such reservoir or receptacle suitable means or apparatus for the frequent and effectual

application of a sufficient quantity of dry earth to any filth which may from time to time be deposited in any receptacle for filth constructed, fitted, or used, in or in connection with such earth closet.

He shall construct such earth closet so that the contents of such reservoir or receptacle may not at any time be exposed to any rainfall or to the drainage of any waste water or liquid refuse from any premises.

7. Every person who shall construct an earth closet in connection with a building shall construct such earth closet for use in combination with a movable receptacle for filth.

He shall construct such earth closet so as to admit of a movable receptacle for filth, of a capacity not exceeding two cubic feet, being placed and fitted beneath the seat in such a manner and in such a position as may effectually prevent the deposit upon the floor or sides of the space beneath such seat, or elsewhere than in such receptacle, of any filth which may from time to time fall or be cast through the aperture in such seat.

He shall construct such receptacle for filth in such a manner and in such a position as to admit of the frequent and effectual application of a sufficient quantity of dry earth to any filth which may be from time to time deposited in such receptacle for filth, and in such a manner and in such a position as to admit of ready access for the purpose of removing the contents thereof.

He shall also construct such earth closet so that the contents of such receptacle for filth may not at any time be exposed to any rainfall or to the drainage of any waste water or liquid refuse from any premises.

Drainage Bye-Laws.—Bye-laws made by the London County Council for regulating the dimensions, form and mode of construction, and the keeping, cleansing and repairing of the pipes, drains and other means of communicating with sewers and the traps and apparatus connected therewith, and approved by the Local Government Board, June 14th, 1901.

1. A person who shall erect a new building and shall cause the subsoil of the site of such building to be drained by means of a drain communicating with any sewer, shall not construct such subsoil drain in such a manner or in such a position as to communicate directly with Drainage of subsoil

such sewer, but shall provide a suitable and efficient trap between such subsoil drain and such sewer.

He shall provide a ventilating opening to such trap at a point in the line of such subsoil drain as near as may be practicable to such trap, and communicating directly with the open air.

He shall cause such ventilating opening to be furnished with a suitable grating or other suitable cover for the purpose of preventing any obstruction in or injury to any pipe or drain by the introduction of any substance through such opening. He shall cause such grating or cover to be so constructed and fitted as to secure the free passage of air through such grating or cover by means of a sufficient number of apertures, of which the aggregate extent shall be not less than the sectional area of the pipe or drain to which such grating or cover may be fitted.

He shall cause such subsoil drain between such trap and such sewer to be constructed in manner prescribed by the bye-laws in that behalf for a drain used for conveying sewage.

He shall cause such subsoil drain above such trap to be formed of suitable earthenware field pipes properly laid to a suitable fall and to discharge into such trap.

Drainage of surface water.

2. A person who shall erect a new building and shall cause any area, forecourt, or paved or unpaved surface within the curtilage of the building to be drained by means of a drain or drains communicating with any sewer shall cause every inlet to such drain or drains to be constructed as a properly-trapped gully, and shall cause such drain or drains to be otherwise constructed in manner prescribed by the bye-laws in that behalf for a drain used for conveying sewage.

Rain-water pipes.

3. Every person who shall erect a new building, and shall provide, in connection with such building, a pipe or channel for the purpose of conveying to any sewer any water that may fall on the roof, shall cause such pipe or channel to discharge in the open air over a properly-trapped gully or into such gully above the level of the water in the trap thereof.

He shall not cause any such pipe or channel to be so constructed as to receive into such pipe or channel any solid or liquid matter from any water closet, urinal, slop or other sink, or lavatory.

Materials, &c., for drains.

4. Except in the case of a drain constructed for the drainage of the subsoil of the site of a building, every person who shall erect a new building shall, in the construction of every drain of such building communicating with a sewer, use good sound pipes formed of glazed stoneware, or of cast iron, or of other equally suitable material.

He shall not construct any such drain so as to pass under any building, except in any case where any other mode of construction may be impracticable.

He shall cause every such drain to be of adequate size, and, if constructed or adapted to be used for conveying sewage, to have an internal diameter of not less than four inches. Size of drain.

He shall also cause every such drain, whether or not constructed or adapted to be used for conveying sewage, to be laid on a bed of good concrete not less than six inches thick, and projecting on each side of the drain to an extent at least equal to the external diameter of the drain. He shall also cause such drain to be laid with a suitable fall. Drain to be laid on concrete. Fall of drain.

If he shall construct such drain of cast iron jointed with socket joints, he shall cause such joints to be not less than 2½ inches in depth, and to be made with molten lead properly caulked, and he shall also cause the annular space for the lead, in the case of three-inch and four-inch pipes, to be not less than ¼ inch in width, and, in the case of five-inch and six-inch pipes, to be not less than ⅜ inch in width. If such drain be jointed with flange joints he shall cause such joints to be securely bolted together with some suitable insertion. Joints of drain.

If he shall construct such drain of stoneware, or material other than metal, he shall cause such drain to be jointed with socket joints properly put together with cement or other equally suitable material.

He shall cause every such drain (other than a drain constructed for the drainage of the subsoil of the site of a building) to be so constructed as to be water-tight and to be capable of resisting a pressure of at least two feet head of water. Drain to be water-tight.

He shall cause good concrete to be filled in so that it shall extend to the full width of the concrete bed already prescribed in this bye-law, and so that such drain shall be embedded to the extent of not less than half its diameter. Concrete to be filled in.

If he shall construct any such drain of cast iron, the thickness and weight of the pipes in proportion to the diameter thereof shall be as follows: Thickness and weight of iron pipes.

Internal diameter. Inches.	Thickness of metal, not less than—	Weight per 9 feet length (including socket and beaded spigot or flanges—the socket not to be less than ⅜ inch thick), not less than—
3	$\frac{5}{16}$ of an inch.	110 lbs.
4	⅜ ,,	160 ,,
5	⅜ ,,	190 ,,
6	⅜ ,,	230 ,,

Thickness, sockets and joints of stoneware pipes.

If he shall construct any such drain of stoneware or material other than metal, the thickness of the pipes, and depths of the sockets, and the annular space for the cement in proportion to the diameter shall be as follows :

Internal diameter. Inches.	Thickness of pipe, not less than—	Depth of socket, not less than, inches—	Annular space for the cement, not less than—
3	$\frac{1}{2}$ of an inch.	$1\frac{1}{2}$	$\frac{5}{16}$ of an inch.
4	$\frac{5}{8}$,,	$1\frac{3}{4}$	$\frac{5}{16}$,,
5	$\frac{5}{8}$,,	2	$\frac{5}{16}$,,
6	$\frac{5}{8}$,,	2	$\frac{5}{16}$,,
9	$\frac{3}{4}$,,	2	$\frac{7}{16}$,,

Drains under buildings.

Where any such drain (other than a drain constructed for the drainage of the subsoil of the site of a building) passes under a building, he shall cause such part thereof as passes under the building to be laid where practicable in a direct line for the whole distance beneath such building, and to be completely embedded in and covered with good and solid concrete at least six inches thick all round.

Provided that in any case where such drain shall be constructed of iron, he shall not be required to cover such drain with concrete, but unless it be carried above ground and also be carried at least at each joint on adequate piers or other sufficient supports, constructed of iron, stone, brick, or cement concrete, it shall be laid on a bed of good concrete in accordance with the requirements of this bye-law relating to drains which do not pass under a building.

He shall whenever practicable cause adequate means of access to such drain to be provided at each end of such portion thereof as is beneath such building.

Composition of concrete.

He shall cause all concrete used in connection with any such drain, whether under a building or not, to be composed of clean gravel, hard brick broken small, or other suitable ballast, well mixed with clean sand and good Portland cement in the proportion of two parts of sand, one part of cement, and six parts of other material.

Inlets to drains to be trapped.

He shall cause every inlet to every such drain, not being an inlet provided in pursuance of the bye-law in that behalf as an opening for the ventilation of such drain, to be properly trapped by an efficient trap so constructed as to be capable of maintaining a sufficient water seal. He shall not construct or fix in or in connection with any such drain, any trap of the kind known as a bell-trap, a diptrap, or a D-trap.

He shall, in every case where any such drain is laid beneath a wall, cause such drain to be protected at the part beneath the wall by means of an arch, flagstone, or iron support, which shall not bear on the drain and shall be of sufficient size and strength to prevent any disturbance of or other injury to such drain. Protection of drain beneath wall.

5. Every person who shall erect a new building shall provide in every main drain or other drain of such building which may immediately communicate with any sewer, a suitable and efficient intercepting trap at a point as distant as may be practicable from such building, and as near as may be practicable to the point at which such drain may be connected with the sewer. Drains to be trapped from sewer.

He shall, except in cases where the means of access to be provided in compliance with the preceding bye-law shall give adequate means of access to such trap, provide a separate manhole or other separate means of access to such trap for the purpose of cleansing it. Access to trap.

6. A person erecting a new building shall cause every means of access provided in compliance with any of the foregoing provisions of these bye-laws to be constructed so as to be water-tight up to the level of the adjoining ground-surface or roadway and to be fitted with a suitable manhole-cover, and, if placed within a building, to be fitted with an air-tight cover.

7. A person who shall erect a new building shall not construct the several drains of such building communicating with a sewer in such a manner as to form in such drains any right-angled junction, either vertical or horizontal. He shall cause every such branch drain or tributary drain to join another drain obliquely in the direction of the flow of such drain and as near as practicable to the invert thereof. No right-angled junctions.

8. Every person who shall erect a new building shall, for the purpose of securing efficient ventilation of the drains of such building communicating with a sewer, comply with the following requirements:— Ventilation of drains.

(i.) He shall provide at least two untrapped openings to the drains, and in the provision of such openings he shall adopt such of the arrangements hereinafter specified as the circumstances of the case may render the more suitable and effectual.

(*a*) One opening being above and near the level of the surface of the ground adjoining such opening shall communicate with the drains by means of a suitable pipe, shaft or chamber, and shall be situated as near as may be practicable to the trap which, in pursuance of the bye-law in that behalf, shall be provided between the main drain or other drain of the Alternative arrangements.

building and the sewer. The point at which such opening communicates with the drain shall also in every case be situated on that side of the trap which is nearer to the building.

The second opening shall be obtained by carrying up from a point in the drains, as far distant as may be practicable from the point at which the first-mentioned opening shall be situated, a pipe or shaft, vertically, to such a height and in such a position as to afford by means of the open end of such pipe or shaft a safe outlet for foul air.

(*b*) In every case where the foregoing arrangement of the openings to the drains may be impracticable or undesirable, there may be substituted the arrangement hereinafter prescribed.

One opening shall be obtained by carrying up from a point, as near as may be practicable to the trap, which, in pursuance of the bye-law in that behalf, shall be provided between the main drain or other drain of the building and the sewer, a pipe or shaft, vertically, to such a height and in such a position as to afford, by means of the open end of such pipe, a safe outlet for foul air. The point at which such opening communicates with the drain shall also in every case be situated on that side of the trap which is nearer to the building.

The second opening, being at a point in the drains as far distant as may be practicable from the point at which such last-mentioned pipe or shaft shall be carried up, shall be above and near the level of the surface of the ground adjoining such opening, and shall communicate with the drains by means of a suitable pipe or shaft.

(*c*) If in any case neither of the two preceding arrangements are desirable, then both the first and second openings may be obtained by carrying up from the points referred to in the previous sub-section suitable vertical pipes or shafts to such heights and in such positions that when either acts as an inlet the other may be a safe outlet for foul air.

Gratings or covers to openings.

(ii.) He shall cause every opening provided in accordance with any of the arrangements hereinbefore specified to be furnished with a suitable grating or other suitable cover for the purpose of preventing any obstruction in or injury to any pipe or drain by the introduction of any substance through any such opening. He shall, in every case, cause such grating or cover to be so constructed

and fitted as to secure the free passage of air through such grating or cover by means of a sufficient number of apertures, of which the aggregate extent shall be not less than the sectional area of the pipe or drain to which such grating or cover may be fitted.

(iii.) He shall not, except where unavoidable, cause any bend or angle to be made in any pipe or shaft used in connection with any of the arrangements hereinbefore specified. No bends or angles in pipes.

(iv.) He shall cause every pipe or shaft which may be used in connection with any of the arrangements hereinbefore specified to have an internal diameter of not less than four inches. Size of pipes.

(v.) He shall cause every pipe or shaft used in connection with any of the arrangements hereinbefore specified to be constructed in the same manner and of the same material and weight as if such pipe or shaft were a soil pipe. Construction, material, and weight of pipes.

(vi.) Provided always, that for the purpose of any of the arrangements hereinbefore specified the soil pipe of any water closet, or the waste pipe of any slop sink constructed or adapted to be used for receiving any solid or liquid excremental filth, in every case where the situation, sectional area, height and mode of construction of such soil pipe or such waste pipe shall be in accordance with the requirements applicable to the pipe or shaft to be carried up from the drains, shall be deemed to provide the necessary opening for ventilation which would otherwise be obtained by means of such last-mentioned pipe or shaft. Use of soil pipes as ventilation pipes.

Provided also that any such soil pipe or waste pipe shall, where such soil pipe or waste pipe shall have an internal diameter of not less than three and a half inches, and shall in all other respects comply with the requirements as to the position, height and mode of construction of the pipe or shaft to be provided for the ventilation of any drain, be deemed to provide adequate ventilation for any drain having an internal diameter of not more than four inches.

9. A person who shall erect a new building shall not construct any drain of such building communicating with a sewer in such a manner that there shall be within such building any inlet to such drain except such inlet as may be necessary from the apparatus of any water closet, slop sink or urinal. No inlets to drains within buildings.

10. A person who shall erect a new building shall cause every pipe in such building for carrying off waste water from every lavatory or sink (not being a slop sink or urinal constructed or adapted to be used Material of waste pipes.

for receiving any solid or liquid excremental filth) to a sewer, to be constructed of lead, iron or stoneware, and to be trapped immediately beneath such lavatory or sink by an efficient syphon trap, which shall be constructed of lead, iron or stoneware, with adequate means for inspection and cleansing, and which shall be ventilated into the external air whenever such ventilation may be necessary to preserve the seal of such trap.

Traps to waste pipes.

He shall not construct or fix in or in connection with such waste pipe, lavatory, or sink, any trap of the kind known as a bell-trap, a dip-trap, or a D-trap.

Waste pipes to discharge in the open air.

He shall cause every pipe in such building for carrying off waste water to a sewer to be taken through an external wall of such building, and to discharge in the open air over a properly-trapped gully or into such a gully above the level of the water in the trap thereof, or over a channel leading to such a gully.

Soil pipes.

11. Any person who shall provide a soil pipe in connection with a new building for the purpose of conveying to a sewer any solid or liquid excremental filth, or shall for that purpose construct a soil pipe in connection with an existing building, shall, whenever practicable, cause such soil pipe to be situate outside such building, and shall construct such soil pipe in drawn lead or of heavy cast iron. Provided that in any case where it shall be necessary to construct such soil pipe within such building, he shall construct such soil pipe in drawn lead with proper wiped plumbers' joints, and so as to be easily accessible.

Situation and material.

Thickness and weight.

He shall construct such soil pipe, whether inside or outside the building, so that its weight, if the pipe be of lead, and its thickness and weight, if the pipe be of iron, in proportion to its length and internal diameter, shall be—

Diameter.	LEAD. Weight per 10 ft. length, not less than	IRON. Thickness of metal, not less than	IRON. Weight per 6 ft. length (including socket and beaded spigot or flanges—the socket not to be less than $\frac{1}{4}$-in. thick), not less than
$3\frac{1}{2}$ inches.	65 lbs.	$\frac{3}{16}$ inch.	48 lbs.
4 "	74 "	$\frac{3}{16}$ "	54 "
5 "	92 "	$\frac{1}{4}$ "	69 "
6 "	110 "	$\frac{1}{4}$ "	84 "

If he shall construct such soil pipe of cast iron with socket joints, he shall cause such joints to be not less than 2½ inches in depth and to be made with molten lead properly caulked, and he shall also cause the annular space for the lead, in the case of 3½-inch and 4-inch pipes, to be not less than ¼-inch in width, and, in the case of 5-inch and 6-inch pipes, to be not less than ⅜-inch in width. If he shall construct such soil pipe with flange joints he shall cause such joints to be securely bolted together with some suitable insertion. Joints.

He shall construct such soil pipe, whether inside or outside the building, so that it shall not be connected with any rain-water pipe or with the waste of any bath, or of any sink other than that which is provided for the reception of urine or other excremental filth, and he shall construct such soil pipe so that there shall not be any trap in such soil pipe or between the soil pipe and any drain with which it is connected. No connection with rain-water and waste pipes. No traps.

He shall cause such soil pipe, whether inside or outside the building, to be circular and to have an internal diameter of not less than 3½ inches, and to be continued upwards without diminution of its diameter, and (except where unavoidable) without any bend or angle being formed in such soil pipe, to such a height and in such a position as to afford by means of the open end of such soil pipe a safe outlet for foul air. Diameter. Outlet.

12. Any person who shall connect a lead soil pipe, waste pipe, ventilating pipe, or trap with an iron pipe or drain communicating with a sewer, shall insert between such lead soil pipe, waste pipe, ventilating pipe, or trap, and such iron pipe or drain, a flanged thimble of copper, brass, or other suitable alloy, and shall connect such lead soil pipe, waste pipe, ventilating pipe, or trap with such thimble by means of a wiped or overcast metallic joint, and shall connect such thimble with such iron pipe or drain by means of a joint made with molten lead, properly caulked; provided always that it shall be sufficient if he shall connect the lead soil pipe, waste pipe, ventilating pipe, or trap with the iron pipe or drain in an equally suitable and efficient manner. Connection of lead soil pipe, &c., with iron drain, &c.

13. Any person who shall connect a stoneware or semi-vitrified ware trap or pipe with a lead soil pipe, waste trap or pipe communicating with a sewer, shall insert between such stoneware or semi-vitrified ware trap or pipe and such lead soil pipe, waste pipe or trap, a socket of copper, brass, or other suitable alloy, and shall insert such stoneware or semi-vitrified ware trap or pipe into such socket, making the joint with Portland cement, and shall connect such socket with the lead soil pipe, waste pipe or trap, by means of a wiped or overcast Connection of stoneware trap of closet, &c., with lead soil pipe, &c.

metallic joint; provided always that it shall be sufficient if he shall connect the stoneware or semi-vitrified ware trap or pipe with the lead soil pipe, waste pipe or trap, in an equally suitable and efficient manner.

Connection of lead soil pipe, &c., with stoneware drain, &c.

14. Any person who shall connect a lead soil pipe, waste pipe, ventilating pipe, or trap with a stoneware or semi-vitrified ware pipe or drain communicating with a sewer, shall insert between such lead soil pipe, waste pipe, ventilating pipe, or trap and such stoneware or semi-vitrified ware pipe or drain, a flanged thimble of copper, brass or other suitable alloy, and shall connect such lead soil pipe, waste pipe, ventilating pipe, or trap with such thimble by means of a wiped or overcast metallic joint, and shall insert the flanged end of such thimble into a socket on such stoneware or semi-vitrified ware pipe or drain, making the joint with Portland cement; provided always that it shall be sufficient if he shall connect the lead soil pipe, waste pipe, ventilating pipe or trap with the stoneware or semi-vitrified ware pipe or drain in an equally suitable and efficient manner.

Connection of iron soil pipe, &c., with stoneware drain, &c.

15. Any person who shall connect an iron soil pipe, waste pipe, ventilating pipe, or trap with a stoneware or semi-vitrified ware pipe or drain communicating with a sewer, shall insert the beaded spigot end of such iron soil pipe, waste pipe, ventilating pipe, or trap into a socket on such stoneware or semi-vitrified ware pipe or drain, making the joint with Portland cement; provided always that it shall be sufficient if he shall connect the iron soil pipe, waste pipe, ventilating pipe or trap with the stoneware or semi-vitrified ware pipe or drain in an equally suitable and efficient manner.

Connection of stoneware trap of closet, &c., with iron soil pipe, &c.

16. Any person who shall connect a stoneware or semi-vitrified ware trap or pipe with an iron soil pipe, waste pipe, trap or drain communicating with a sewer, shall insert such stoneware or semi-vitrified ware trap or pipe into a socket on such iron soil pipe, waste pipe, trap or drain, making the joint with Portland cement; provided always that it shall be sufficient if he shall connect the stoneware or semi-vitrified ware trap or pipe with the iron soil pipe, waste pipe, trap or drain in an equally suitable and efficient manner.

Ventilation of trap of water-closet.

17. Any person who shall construct any water-closet, the soil pipe of which shall communicate with any sewer and shall be in connection with any other water-closet, shall cause the trap of every such water-closet to be ventilated into the open air at a point as high as the top of the soil pipe, or into the soil pipe at a point above the highest water-closet connected with such soil pipe, and so that the ventilating pipe shall have in all parts an internal diameter of not less than two inches and shall be connected with the arm of the soil pipe or the trap at a

point not less than three and not more than twelve inches from the highest part of the trap and on that side of the water seal which is nearest to the soil pipe. He shall cause the joint between the ventilating pipe and the arm of the soil pipe or the trap to be made in the direction of the flow.

He shall construct such ventilating pipe in drawn lead or of heavy cast iron. Provided that in any case where it shall be necessary to construct such ventilating pipe within a building he shall construct such ventilating pipe in drawn lead.

He shall construct such ventilating pipe, whether inside or outside a building, so that if the pipe be of lead its weight shall not be less than 45 lbs. per twelve feet length, and if the pipe be of iron its thickness shall not be less than $\frac{3}{16}$-inch and its weight not less than 25 lbs. per six feet length.

He shall in all cases cause the joints in and the connections to such ventilating pipe to be made in the same manner as if such ventilating pipe were a soil pipe.

Slop sinks for filth and urinals.

18. A person who shall erect a new building, and shall construct in connection with such building a slop sink or urinal constructed or adapted to be used for receiving any solid or liquid excremental filth for conveyance to any sewer, shall construct or fix immediately beneath such slop sink or urinal an efficient syphon trap, so constructed as to be capable of maintaining a sufficient water seal between such slop sink or urinal and any drain, soil pipe or waste pipe in connection therewith. He shall not construct or fix in or in connection with such slop sink or urinal any trap of the kind known as a bell-trap, a dip-trap or a D-trap.

He shall as regards the ventilation of the trap of such slop sink or urinal and the construction of the waste pipe of such slop sink or urinal comply with all the requirements of the preceding bye-laws which are applicable to the ventilation of the trap of a water-closet and the construction of a soil pipe, always provided that the internal diameter of the waste pipe of any such slop sink or urinal shall not be less than three inches, and where the internal diameter of such waste pipe is three inches the weight of such pipe for every ten feet of length shall, if such waste pipe be constructed of lead, be not less than 60 lbs., and if such waste pipe be constructed of cast iron the weight of such pipe for every six feet of length shall be not less than 40 lbs.

Sewage Disposal.—The following are some of the methods of disposing of the excreta and sewage of towns:—

1. By using the matter as a crude manure, or making

it into a compost and digging it into the ground, as in the privy and earth closet system.

2. By discharging the crude sewage into the sea, as is adopted by many seaside towns.

3. By treating the raw sewage with chemicals, which precipitate the solids and suspended matters. The precipitated sludge is carried away and deposited in the sea at a distance from the land, and the purified effluent is discharged into the tidal river between high water and half ebb, so that it mixes with and is carried away by the falling tide. London sewage is treated in this manner.

4. By straining the grosser solid matters from the crude sewage, and distributing the liquid by means of carriers over large tracts of land to nourish vegetation, the roots of which absorb the suspended matter. The fluid filters through the land into under-drains, and eventually passes into the nearest watercourse. This is known as the broad irrigation system, and can only be adopted where the topography and nature of the land favour such treatment. This system is successfully worked at Croydon.

5. By chemical precipitation, combined with land irrigation. The suspended solids are precipitated by chemicals; the sludge is then removed and used as a crude manure. The liquid is collected in an automatic acting tank as Fig. 598, and periodically discharged into channels or carriers constructed on a piece of prepared land, with a system of under drains at a depth of about 6 feet, and through which the filtered effluent passes to the nearest watercourse. This method is known as downward intermittent filtration. Sometimes the chemical precipitation is omitted, the grosser solid matters only being removed by strainers.

6. By using ferrozone to precipitate and deodorize the solids, the liquids being clarified, or filtered, and aërated by passing them through filters charged with polarite, or a

rustless magnetic oxide of iron. This is known as the International Method. The sludge is compressed, dried, and ground into powder, and sold for manure.

7. By bacterial treatment. Sewage always contains micro-organisms, which have a solvent action on the organic matter it contains. By passing the sewage into a filter bed filled with suitable material, such as broken coke, burnt clay, ballast, or similar matters, the micro-organisms will eventually propagate in the filtering material and act upon the suspended matters in the sewage. Newly constructed filters are of little value, but those that have been in use for some time are filled with colonies of bacteria. The growth, or multiplication, of the bacteria is dependent upon the amount of the organic matter in the sewage and the amount of oxygen conveyed to the bacteria in the body of the filter.

Sewage-purifying bacteria are of several kinds. Amongst them are those which thrive without air, and have a septic action on the organic matter in the sewage; and those which require air and digest the sewage without first reducing it to a rotten condition. With a septic treatment the sewage is first subjected to the influence of anaërobic organisms and then passed through filters which contain aërobic organisms. In many sewage installations the crude sewage is passed directly into aërobic filter beds, and is not subjected to a preliminary septic treatment. This latter system is being experimentally tried by the London County Council at their sewage outfall works at Barking. Very little sludge is formed when the bacterial treatment of sewage is properly carried out.

Cesspools. — The disposal of the sewage of isolated country residences and mansions having a water supply is sometimes carried out as follows:—The drain is continued from the house for a distance of 100 feet or more

for conveying the sewage through a disconnecting trap into the cesspool. The cesspool should be not less than 100 feet from any well, spring, or stream of water.

The cesspool is made sufficiently large to contain a quantity of sewage equal to a week or three months' accumulation as may be desired. The sewage is pumped out by a chain-pump and put upon the land. The cesspool is used instead of the public sewer. The cesspool is built with impervious sides and bottom, with good brickwork bedded and grouted in cement, properly rendered inside with cement, and with an outside backing of at least 9 inches of well-puddled clay around and beneath such brickwork, to make the cesspool watertight. Figure 606 illustrates this arrangement.

The cesspool should not be ventilated; but to prevent it being "air-bound" a small "breathing hole," filled with broken bricks or ballast, can be constructed underground either over or at one side of the cesspool. A cesspool can be arranged as a septic tank, and have an overflow pipe (with the end submerged below the scum on the surface of the sewage) to empty into a filter bed, or into agricultural land by a system of sub-irrigation pipes.

The following are the Bye-laws of the London County Council with respect to cesspools:—

20. Every person who shall construct a cesspool in connection with a building, shall construct such cesspool at a distance of one hundred feet at the least from a dwelling-house, or public building, or any building in which any person may be, or may be intended to be employed in any manufacture, trade, or business.

21. A person who shall construct a cesspool in connection with a building, shall not construct such cesspool within the distance of one hundred feet from any well, spring, or stream of water.

22. Every person who shall construct a cesspool in connection with a building, shall construct such cesspool in such a manner and in such a position as to afford ready means of access to such cesspool, for the purpose of cleansing such cesspool, and of removing the contents

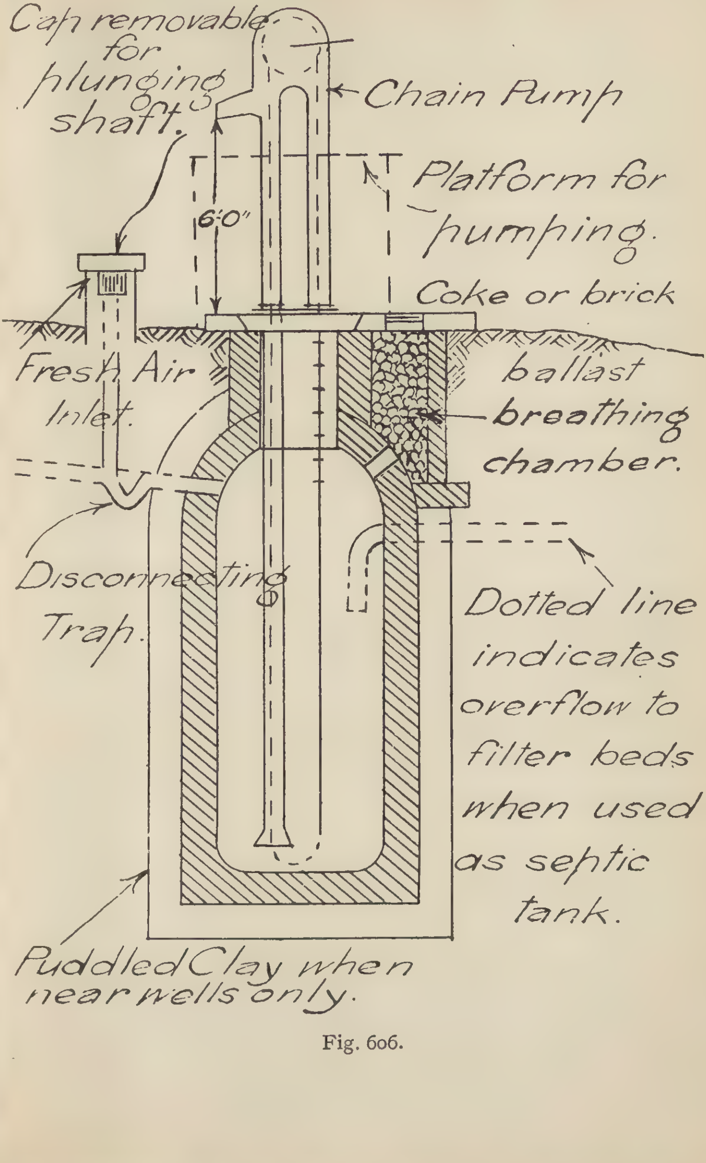

Cap removable for plunging shaft.
Chain Pump
Platform for pumping.
6'0"
Coke or brick ballast breathing chamber.
Fresh Air Inlet.
Disconnecting Trap.
Dotted line indicates overflow to filter beds when used as septic tank.
Puddled Clay when near wells only.

Fig. 606.

thereof, and in such a manner and in such a position as to admit of the contents of such cesspool being removed therefrom, and from the premises to which such cesspool may belong, without being carried through any dwelling-house, or public building, or any building in which any person may be, or may be intended to be, employed in any manufacture, trade, or business.

He shall not in any case construct such cesspool so that it shall have, by drain or otherwise, any means of communication with any sewer or any overflow outlet.

23. Every person who shall construct a cesspool in connection with a building, shall construct such cesspool of good brickwork bedded and grouted in cement, properly rendered inside with cement, and with a backing of at least nine inches of well-puddled clay around and beneath such brickwork, and so that such cesspool shall be perfectly water-tight.

He shall also cause such cesspool to be arched or otherwise properly covered over, and to be provided with adequate means of ventilation.

Minimum Velocity of Sewers and Drains.—The minimum velocity to effectively scour a sewer or drain is given by Parkes as $2\frac{1}{2}$ feet to 4 feet per second. From this the fall or height required may be obtained by Eytelwein's formula when the drain is flowing full bore.

$$v = 50\sqrt{\frac{d\,H}{L + 50\,d}}$$

v = velocity in feet per second
d = diameter of pipe in feet
L = length of pipe in feet
H = head or fall of water in feet.

Example.—What is the fall required to obtain a velocity of 4 feet per second in a 6-inch pipe, 100 feet long?

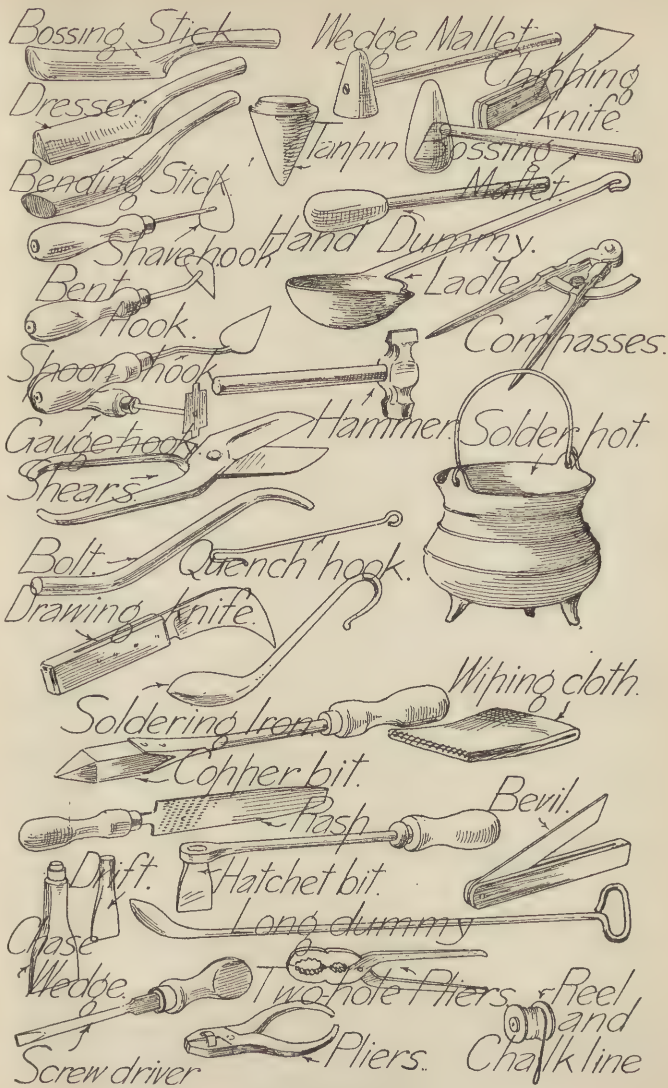
$$v = 50\sqrt{\frac{d\,H}{L + 50\,d}}$$

$$4 = 50\sqrt{\frac{\cdot 5 \times H}{100 + 50 \times \cdot 5}}$$

$$\frac{4}{50} = \sqrt{\frac{H}{125}}$$

$$\frac{16}{2{,}500} = \frac{H}{250}$$

$$H = 1\cdot 6\text{, or 1 foot in } 62\tfrac{1}{2}\text{ feet.}$$



Figs. 607 to 639.

For the usual velocities in practice Eytelwein's formula is not considered so exact as Neville's formula, which is as follows for open channels and pipes :—

Let V = velocity in feet per second

R = the hydraulic radius or mean depth in feet

$= \frac{\text{sectional area}}{\text{wetted perimeter}}$ in pipes flowing full or half bore $= \frac{\text{dia. in ft.}}{4}$

S = The sine of the inclination of the pipe

$= \frac{\text{total fall}}{\text{total length}}$

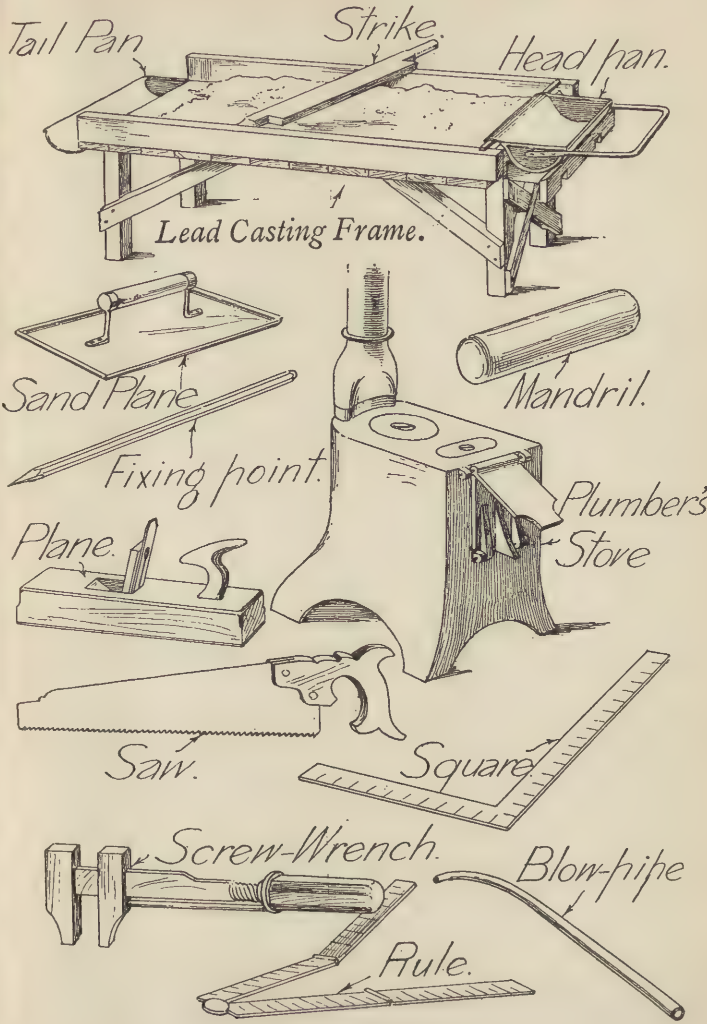
then $V = 140 \sqrt{RS} - 11 \sqrt[3]{RS}$

It will be found from this formula that—

4 in. pipes	with a	fall	of	1 in 40
6 in.	,,	,,	,,	1 in 60
9 in.	,,	,,	,,	1 in 90
12 in.	,,	,,	,,	1 in 120

running full or half-bore will flow with a velocity of nearly 5 feet per second.

Plumber's Tools.—Figures 607 to 650 show the ordinary tools used by plumbers. The bossing stick and dresser are made of boxwood, and are used for bossing or working up sheet lead into the various forms for which it is employed; the chase wedge and drift are used for working the lead into corners. The wedge mallet and bossing mallet are used for hitting the preceding tools, and are often used for working the lead direct. The bending stick is used for bending of lead pipes. The tanpin is used for opening the end of lead pipes preparatory to joining them together. The chipping knife is used with the hammer for cutting lead. The drawknife is for cutting sheet lead, and is used with the hand. The saw is used for cutting pipes. The shears are used for cutting sheet metals generally. Hand dummies and long dummies are used for bending large lead pipes. The bolt is used for opening holes in the side of pipes preparatory to making branch joints. The copper bit and hatchet bit and blowpipe are used for soldering, usually



Figs. 640 to 650.

where it is difficult or unnecessary to make a wiped joint. The solder-pot is used to hold the solder during the process of melting. The quench hook is used for carrying the solder-pot when it is hot. The ladle is used for conveying the solder from the solder-pot to the joint about to be made. A plumber's stove is for heating the solder. Wiping cloths are used for moulding the solder about a joint. A soldering iron is used for keeping the solder in a plastic condition while a joint is being wiped. The shave hook, bent hook, spoon hook, and gauge hook are used for shaving the coating of lead oxide from the lead surfaces about to be soldered. The rasp is used for preparing the ends of pipes for jointing. The fixing points are used for driving into the joints of brick-work, or into any surface, in order to obtain a temporary fixing by tying the lead pipes while joints are being made.

The rule, compass, square, bevel, and chalk line are for measuring and setting out work. The screw wrench and two-hole pliers are for turning nuts, collars, etc., on brass or iron connections. The small pliers are for cutting and bending wire. The casting bench is used for casting sheet lead, and consists of a bench, the bottom of which is covered with moistened sand. The surface of the sand is made even with the strike, the handles of the latter working on the sides of the trough. After the striking, the surface of the sand is smoothed with the sand plane. The molten metal is ladled into the head pan, which must be level. This is tilted, and the metal is caused to flow evenly over the sand. It is then struck off to an even thickness with the strike, all the surplus metal being pushed into the tail pan. When the metal has cooled sufficiently the sheet is rolled up and removed from the bench. The lead plane has a steel face, and the iron steeply pitched, and is used for planing the edges of sheet lead straight. The mandrel is used for taking bruises out of lead pipes. The hammer and screwdriver are used as in other trades.

CHAPTER XVI.

HOT WATER APPARATUS.

Hot Water Supply.—The hot water for domestic purposes in a small building is usually heated by the kitchen fire.

In large buildings, where considerable quantities of water are required, a separate boiler is used for heating the water. In such cases the kitchen boiler, or boilers, is retained for heating the water for kitchen and scullery use or for generating steam for cooking purposes. With the exception of a small copper coil, or towel warmer, in a bath room, the water from a kitchen boiler should never be used for heating coils or radiators in rooms, corridors, and passages.

If much hot water is required, an independent boiler is to be preferred.

Radiation and Convection.—Heated bodies transmit heat by radiation, by convection, and by conduction. Radiant heat passes from one body to another without affecting the intervening atmosphere. Conducted heat passes from one body to another, or from one part to another, which is at a lower temperature, by actual contact. Atmospheric air, gases, and fluids generally are heated by contact with bodies at a higher temperature than themselves. The heated molecules of either air or water are expanded and rise in the larger volumes which are not heated. The rising molecules take the heat they have absorbed with them, and set up what are known as convection currents.

The radiation and convection methods of heating are

respectively termed the direct and indirect methods of conveying heat from one place to another.

If a room is warmed by placing a heated body within it, the room is said to be heated by radiation or the direct method. But if warmth is obtained by introducing air heated by a fire or other heat source fixed in another place, the system would be termed the convection or indirect method of heating.

The two methods of heating by radiation and convection are sometimes combined.

Convection currents will be set up in the air in a room by the presence of people in the room, or by a heating medium, such as a stove or a gas burner situated in the room. But convection currents cannot be maintained in a room unless provision is made for the air already in the room to escape, and thus make room for the heated air to enter.

Hot Water Circulation.—If a vertical tube containing water is heated at the bottom, the heated particles of water will ascend in the centre, rise to the top, become cooled by giving off their heat through the external surface of the tube, and then descend at the sides of the tube towards the bottom.

If a bent tube of the form of a siphon is connected to the upper side of a closed vessel, and the whole is filled with water, and heat is applied to the bottom of the vessel, there will be motion in the water, caused by the convection currents which will be set up. The heated water will rise up one leg of the siphon and return through the other leg into the vessel to be again heated. The direction of the current in the siphon is ensured by connecting the flow end of the pipe to the upper side of the vessel and the return end of the tube to the lower side of the vessel. From the highest point of the siphon a vertical tube or

expansion pipe should be fitted to allow for the air to escape and for the expansion of the water and thus prevent damage to the tube or vessel.

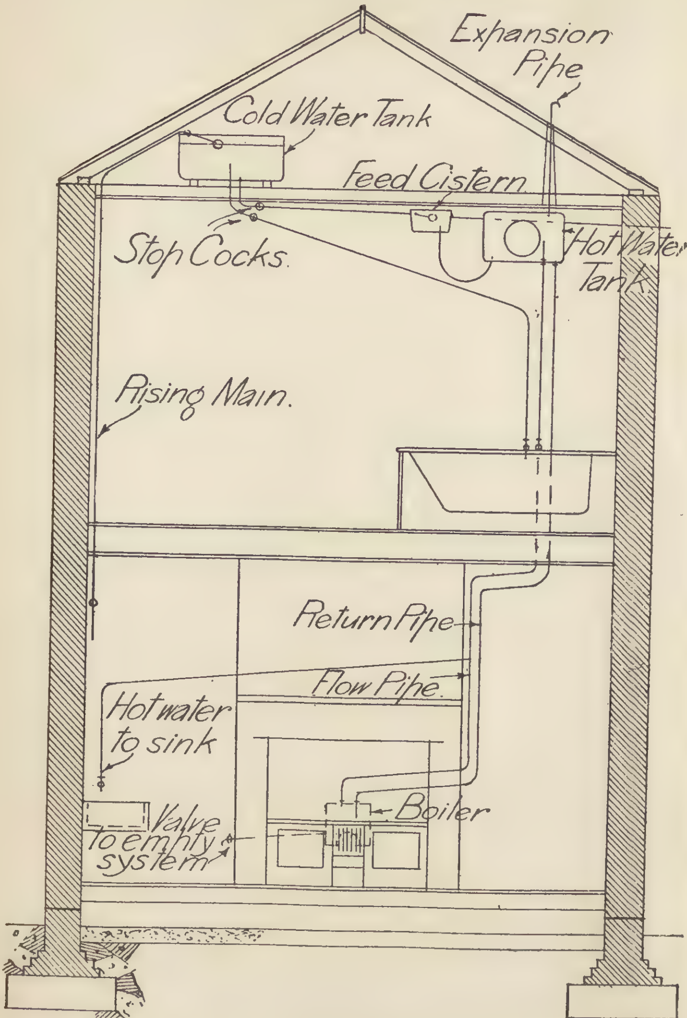
Hypocaust Method.—The Hypocaust method of warming consists in passing air through tubes surrounded by a fire. The heated air is conveyed through ducts to the lower part of the room to be heated. Provision is made in the higher part of the room for the escape of vitiated atmosphere. This is a very old method, but is now condemned as being very unhealthy, owing to the atmosphere being robbed of its oxygen and the dust and organic matter in the air being burned. Neither is the heated air in a proper condition of humidity to be suitable for breathing.

Incrustation of Pipes.—Most waters contain an appreciable quantity of bicarbonate of lime, and are known as "hard-waters." When such water is heated to boiling point a deposit of $CaCO_3$ forms a hard crust on the interior of the boiler and pipes, and this requires frequent removal. In London the removal of this lime deposit is occasionally necessary. For the removal of the deposit, or fur, man-lids in the boilers, cylinders, and tanks, and screwed connectors in the pipes are provided. Rain-water gives little or no deposit, but corrodes the metal of which the boiler, pipes, etc., are made.

Classification. — There are four general methods of heating water for domestic use:—hot water, low pressure; hot water, high pressure; steam, low pressure; steam, high pressure.

Hot Water, Low Pressure.—Figure 651 shows what is known as an ordinary tank system for hot water supply for domestic purposes. The boiler is of welded wrought iron or copper, and is placed behind the kitchen fire. Two cisterns of galvanized wrought iron are usually fixed, the former for cold water, and the latter for hot water.

HOT WATER SUPPLY, "LOW PRESSURE."
"TANK" ARRANGEMENT.



VERTICAL SECTION.
Fig. 651.

The cold water cistern is supplied from the Water Company's main, or other source, through a ball-cock, and is connected to the hot water tank directly, or through a feed cistern with a ball valve. The latter is preferable, as the heated water cannot "work" back into the cold water cistern.

A "flow pipe" is taken from the top of the boiler to the upper part of the hot water tank, and a "return" pipe from the bottom of the hot water tank to the boiler, being continued down inside the boiler for about 6 inches.

"Flow and return" pipes, in all systems, should have a gradual rise or fall respectively, so that all air can escape out of the pipes, and no check is offered to the free flow of the convection currents in the water.

The flow and return pipes should be made of galvanized wrought iron, steam quality, or of copper well tinned inside.

Pipes are branched from the "flow" pipes to supply the draw-off cocks to the sinks, and to the bath.

The apparatus being filled with water, and the fire lighted, the heat from the fire is conducted by the metal to the water inside the boiler. From what has already been said, the circulation of the heated water in the boiler and pipes by convection currents may be readily understood. The hot water tank on the upper ends of the flow and return pipes forms a store of water more or less heated.

The disadvantage of the tank system is that should the ball-cock become fixed and fail to act, the tank and pipes could be emptied of water to the level of the branch leading to the lowest draw-off cock. And the water remaining in the boiler would, by the heat of the fire, soon be evaporated, and the boiler injured by the heat of the fire. There is risk, too, of the boiler being burst by the sudden expansion of water on being converted to steam if any water should enter the empty boiler when it is in a

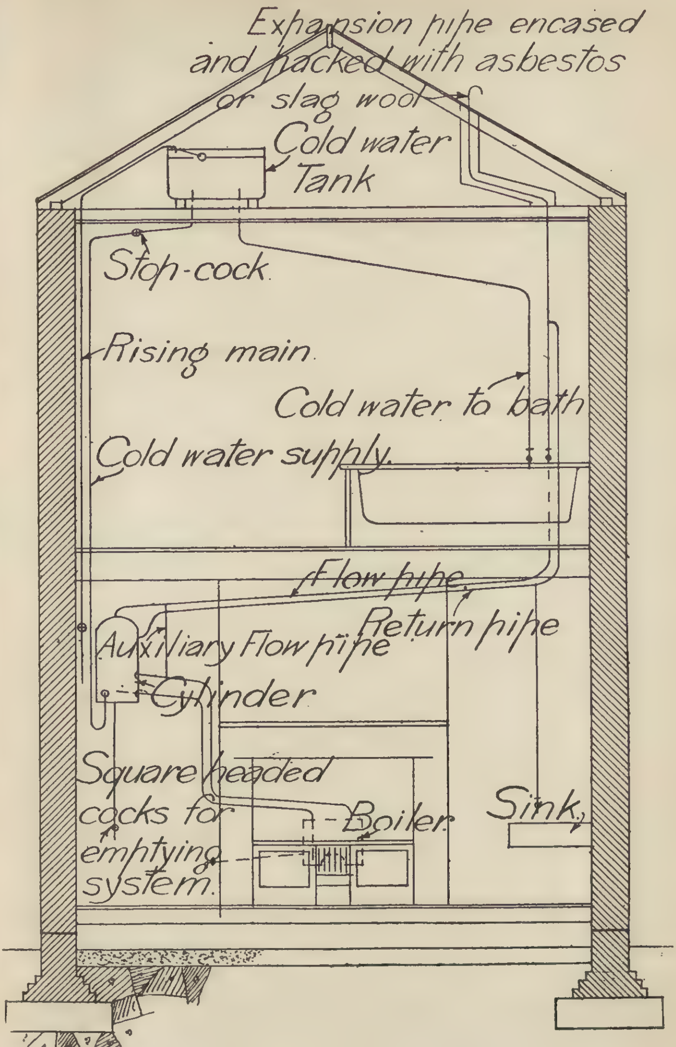
heated condition. The cistern, tank, and pipes should be placed in such positions that the contained water is not liable to become frozen, or they should be protected from that danger by being encased.

Safety Valve.—Should the water in the pipes become frozen, or the pipes clogged or blocked in any way, the expansion of the water on lighting a fire under a boiler which has no vent would burst the boiler. This may be prevented by the use of a safety valve fixed on the top of the boiler. The dead-weight kind of valve is the best. The dead-weight valve should always be fixed where it can be seen. In the cylinder system if the latter is near to the boiler the safety valve is often fixed on the top of the cylinder.

Cylinder System.—An improvement on the tank system is shown in figure 652, and is known as the "cylinder system."

The cylinder is placed in the kitchen or scullery as near to the boiler as convenient. The cold water tank and the flow and return pipes are connected as shown, and an auxiliary flow pipe is also connected. The latter pipe acts as a bye-pass by which it is possible to obtain hot water in the morning direct from the boiler before the contents of the cylinder are heated. The expansion pipe is taken through the roof and encased to protect the inside water from freezing in the winter time. The return pipe is taken to the cylinder, which it enters just below the domed top. Branch pipes are fixed as shown to supply the bath, and sink cocks. A stop-cock should be placed in the cold water supply to cylinder, to shut off the cold water supply and thus enable repairs to be effected to cylinder and boiler without emptying the cold water cistern. The cock should have a loose key, and be kept in the charge of a responsible person.

HOT WATER SUPPLY AND WARMING, "LOW PRESSURE."
"CYLINDER SYSTEM."



VERTICAL SECTION.
Fig. 652.

U U

The advantages of this system are, the cylinder being close to the boiler the water heats rapidly, and the contents are not liable to become frozen; the cylinder cannot be emptied through the draw-off cocks, and it holds a store of water which, in the event of the ball-cock becoming fixed, prevents the burning out of the boiler.

Expansion Pipe.—To admit of expansion of the water and any steam or air to escape, the expansion pipe should be carried up 5 or 6 feet above the level of the water in the cold water cistern. The expansion pipe should be carried through the roof, and be encased and packed with poor heat-conducting material, for reasons before mentioned.

Dimensions of Parts.—The cold water cistern should be about 4 feet 6 inches × 3 feet 6 inches × 2 feet 6 inches, and the hot water tank 2 feet × 2 feet × 2 feet. The boiler about 1 foot 6 inches × 1 foot 3 inches × 9 inches, and the cylinder to contain about 40 gallons. The flow and return pipes $1\frac{1}{4}$ inches, expansion pipe $1\frac{1}{4}$ inch, draw-off to bath 1 inch, to sink and jamb $\frac{3}{4}$ inch, and lavatory $\frac{1}{2}$ inch. But these dimensions and sizes should always be calculated so as to be suitable for the requirements of the various cases.

Maximum Temperature.—To obtain the hottest water in all systems, the hot water should be drawn off the "flow" pipes.

Hot Water, High Pressure.—The system known as "Perkins'," or "Small bore," is shown in figure 653, and consists of a boiler composed of a coil of strong wrought-iron pipe screwed together with sockets and having right and left hand threads, the pipes being $\frac{7}{8}$ inch bore, and $1\frac{5}{16}$ inches outside diameter, and having a total content equal to about $\frac{1}{6}$ of the entire apparatus. The pipe coil is set in a firebrick furnace, fixed in the basement of the building, and is connected with similar pipe to the fittings on the various floors. On the various floors coils of pipe are inserted in cold water tanks, the contents of which they

heat. Hot water is drawn from the tanks to supply the baths and sinks. The return pipe is dipped at its lowest part to prevent the circulation acting backwards. The heating pipes, which contain about 1 gallon of water to each 40 feet run, are filled and hermetically sealed, so that no waste or evaporation of water can take place. Provision is made for the expansion of the heated water by an expansion chamber, the capacity of which equals from $\frac{1}{10}$ to $\frac{1}{20}$ the contents of the entire apparatus. The whole of the pipes are tested to a pressure of from 2,000 to 3,000 lbs. per square inch.

A very high temperature can be produced with this apparatus, the temperature varying with the pressure exerted by the excessive heating, from 200° to 500° Fahr.

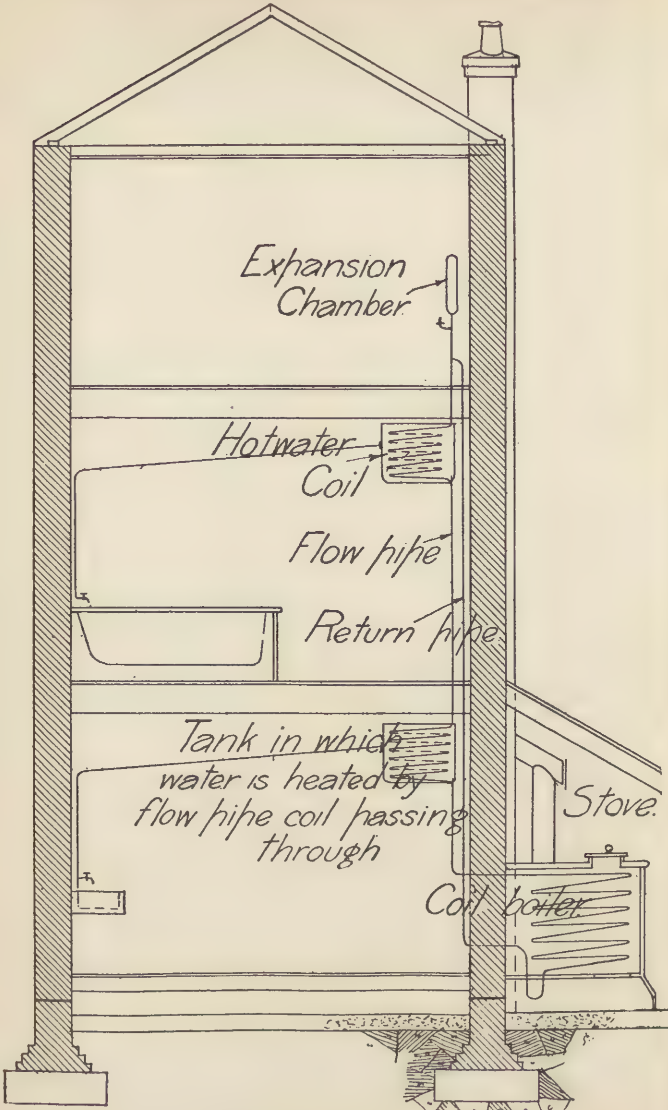
The temperature can be raised so high that it is always advisable to fix the pipes some little distance from any woodwork, or place asbestos round the pipes when in contact with any inflammable material.

This system heats rapidly, and can be applied in positions where the larger pipes of the low pressure system would not be so suitable. It is sometimes used for heating churches, public institutions, also for drying processes, and is specially to be recommended for the latter.

If the high pressure system of heating is adopted for warming buildings where the water for domestic use is heated in a similar manner, a separate system of pipes and coils must be installed for each system.

Steam, Low Pressure.—This system of heating consists of a boiler, usually tubular, placed in the basement, and from which wrought-iron pipes are conducted to the various rooms, and there connected to coils of wrought-iron or copper, or to cast-iron radiators and return pipes from the radiators taken back to a steam trap, the overflow from which is taken to a sump and pumped back into the boiler, or returned to the boiler by a steam injector.

Hot Water Supply and Warming,
"High Pressure" or "Small Bore System."



Vertical Section.

Fig. 653.

The pressure at which a low pressure steam apparatus works is from 5 to 10 lbs. per square inch, and the arrangement requires careful fitting and constant attention in order to maintain a uniform heat and to avoid accidents.

Steam, High Pressure.—High pressure steam is usually supplied direct from a steam boiler, or from the exhaust steam of a steam engine. The working pressure varies from 10 to 50 lbs. per square inch. The steam is conveyed by wrought-iron pipes to coils or radiators, placed in the positions to be warmed, and which have to be made strong enough to safely withstand the pressure exerted.

Warming by steam, low and high pressure, by the direct, indirect, or combined methods, is often used for workshops, drying rooms, public buildings, and large establishments (used for manufacturing purposes), and also for producing dry air at high temperatures, as in Turkish baths.

As the heat from steam radiators is quickly diffused in the air, the ventilating arrangements in rooms should be under good control for either opening or closing. By steam a building can be quickly warmed. But as the steam quickly condenses when the boiler fire is damped, it follows that there is no stored heat in the radiators, as is the case with hot water heating systems.

In steam heating installations noises are often heard which are very objectionable, through the condensation which takes place in the pipes. But these noises can be avoided by carefully aligning the pipes and making provision for disposing of the condensed water.

Best Method for General Purposes.—The "low pressure" hot water heating system is the best for small buildings and residences for the following reasons:—It can be applied to any description of building, public, private, horticultural

or manufacturing; the heat given off is healthy, mild, and agreeable, the temperature of the pipes seldom exceeding 190° Fahr., and never 212°, consequently the air which comes into contact with them is gradually warmed and not scorched, and the temperature in the pipes can be gradually raised, or lowered, or evenly maintained. The small amount of fuel and labour required, and the freedom from the generation of those gases which are injurious to plants, and the quality of the heat given off, render low pressure hot water heating systems the most satisfactory of all for ordinary use. Where excessively high temperatures are required, super-heated water or steam installations give the most satisfactory results.

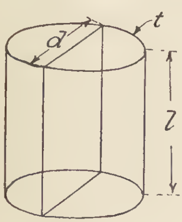


Fig. 654.

Hot Water Low Pressure.—The hot water low pressure system of heating is best for large buildings if the heat is to be sustained for a considerable time. If hot water is used for heating dwelling-houses, the heating coils, or radiators, should be fixed in the entrance hall near the staircase, and in the corridors and passages, or in the large reception rooms. But not in bedrooms.

Strength of Pipes.—Pipes under hydraulic pressure frequently fail and break with a longitudinal fracture. Their ultimate resistance may be calculated by the formula—

$$p \times d \times l = 2\, l\, t\, f_t$$

when

p = pressure per unit of area upon diametral plane
d = width of diametral plane as shown in figure 654
l = length of diametral plane
t = thickness of pipe
f_t = ultimate resistance in tension or safe resistance to tension, and values of which for cast iron, wrought iron and steel are given on page 128.

Example.—To what head of water could a 12-inch cast-iron pipe of $\frac{5}{8}$-inch metal be exposed without the stress on the metal exceeding 2,000 lbs. per square inch? Then by formula

$$p \times d \times l = 2 l t f_t$$
$$p = \frac{2 t f_t}{d}$$
$$p = \frac{2 \times \frac{5}{8} \times 2000}{12}$$
$$p = 208\tfrac{1}{3} \text{ lbs. per square inch.}$$

The pressure is therefore $208\frac{1}{3}$ lbs., or $208\frac{1}{3} \times 16$ ozs. per square inch.

Let head of water $= h$ and $w =$ weight of cubic inch of water $= \frac{1000}{1728}$ ozs.

then—

$$h = \frac{p}{w}$$
$$h = \frac{208\frac{1}{3} \times 16}{\frac{1000}{1728}}$$
$$h = \frac{208\frac{1}{3} \times 16 \times 1728}{1000}$$
$$h = 5760 \text{ inches}$$
$$= 480 \text{ feet.}$$

VENTILATION.

Definition.—Buildings constructed so that the internal air is constantly changed and is vitiated to so slight an extent that any ill-effects are scarcely perceptible, are said to be ventilated.

Buildings to merit the term healthy should satisfy the following conditions:—(1) The internal air should be pure and constantly changed by everflowing currents without "draughts"; (2) the building should be clean and dry;

(3) no decomposition of the building materials should be taking place, and it is especially important that all woodwork should be exposed to a current of dry air; and (4) all soil and waste pipes and drains should be ventilated and trapped. All the above except No. 1 have been fully dealt with; the 1st will now be discussed.

Pure Air Standard.—The degree of purity of the air is determined in most instances according to the quantity of carbon dioxide present, the standard of external atmospheric air being taken as containing not more than ·04 per cent. of CO_2.

Air within buildings containing ·06 per cent. of CO_2 may be considered injurious, but with ·09 or ·1 per cent. it becomes stuffy and unbearable. It becomes evident, therefore, that the air in habitable rooms should never contain more than ·06 per cent. of CO_2. The air should be kept in this condition by ventilation and without any draught perceptible to the senses being occasioned, the greatest permissible velocity of the air currents being 3 feet per second, when the temperature is between 50° and 60° Fahr. At lower temperatures the same rate of motion would be considered as draughty. Pure air in buildings is necessary for the sustenance and improvement of health, for the perfect combustion of fuel, and for the preservation of the materials of which the buildings are constructed.

Oxygen Supply for Fuel.—If a chamber has sufficient outlets independently of the fireplace, the necessary oxygen for the combustion of fuel is best supplied to the fire direct from outside the house by special air ducts discharging through the fireplace jambs, as shown in figures 655 and 656, the supply being regulated by a sliding valve. Where provision is not made for supplying the fire and the draught up the chimney, the air is drawn through the crevices of imperfectly fitting window sashes and doors, and this often causes unpleasant draughts.

Density of Gases.—It will be found useful to note the comparative densities of the gases which constitute atmospheric air, many of which are considered objectionable and unsuitable for breathing.

Pure atmospheric air	.. ..	14·4
Carbon dioxide	(CO_2)	22
Water vapour	(H_2O)	9
Ammonia gas	(NH_3)	8½
Nitrous acid	(HNO_2)	23½
Sulphuretted hydrogen	(H_2S)	17
Sulphur dioxide	(SO_2)	32

Sources of Atmospheric Impurities.—Carbon dioxide is given off in the breath of mankind and all living animals, in the combustion of fuel, in the burning of gas, etc., and in the decay of organic matter.

Water vapour arises from damp soils, marshy lands, lakes, ponds, and streams, and is harmful only when the air is overcharged with it, and which leads to colds, chills, rheumatism, etc. Water vapour is also given off from people's lungs in the act of breathing.

Ammonia is formed during the decomposition of moist animal and other matters, which contain hydrogen and nitrogen, and is very noticeable in unventilated stables, cowbyres, piggeries, and urinals. Sulphur dioxide will be found in rooms where coal gas or coke is burning, and in the neighbourhood of gas manufactories.

Sulphuretted hydrogen is given off from decaying animal and vegetable matter, and is produced in large quantities in cesspools and in unventilated sewers and drains.

Carbon dioxide is to a certain extent decomposed by the agency of sunlight on the chlorophyll of plant leaves.

Rise or Fall of Gases.—Air and gases in rooms when heated above the temperature of the external air will

have a tendency to rise, but at the same or a lower temperature they will descend to low levels, where they are breathed by the occupants of the rooms. Hence the necessity in the natural method of ventilation of introducing

Fig. 655.

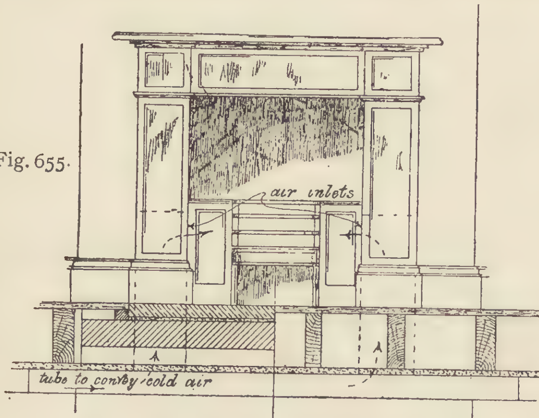
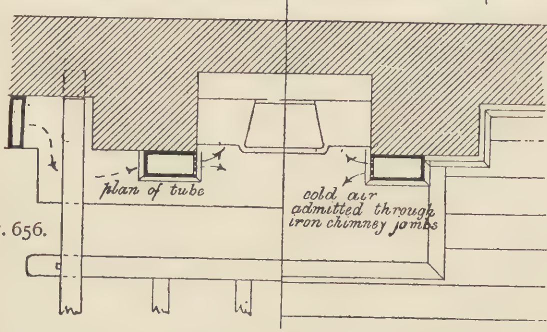


Fig. 656.



fresh air at a low level, warming the internal air, and exhausting the heated and fouled air at a high level, to prevent the respiration of stagnant air which is charged with offensive gases.

Changing of Atmosphere.—To change the air in a room ventilated by the natural method outlets should be provided

at the highest, and inlets at the lowest, level of the chamber. In order to prevent the incoming cool air impinging against the bodies of the persons in the room, it is advisable to break up and distribute the currents as much as possible. The incoming air should not follow a direct path to the outlet, but should thoroughly mix with the air in the room, and travel at a slow rate of speed to the outlets.

It is better to have a number of small air inlets and outlets than to have one large inlet and one large outlet. A more equal diffusion and change of air in a room is thus effected with a low velocity, and offensive draughts are avoided.

Natural and Artificial Ventilation.—Ventilation may be obtained either by natural or by artificial means. When air movements are caused by the difference in the weight of two columns of air, one being heated, the ventilation is said to be natural. If the air is put into motion by mechanical appliances, such as fans or screws, the ventilation is said to be artificial.

Natural methods of ventilation are the least expensive, but are difficult to control.

Heat may be advantageously applied to assist the natural ventilation in buildings, such as theatres, where large sunburners near the ceilings create ascending currents in the air, and which pass through outlets provided for the purpose. These currents exhaust the lower vitiated air, which, in its turn, is replaced by warm or cold air introduced at low levels.

The current of air in a ventilating shaft is sometimes assisted by burning gas in the shaft or by fixing hot water or steam pipes in the lower part of the flue.

Artificial methods of ventilation, such as by fans, exhaust pumps, stationary or revolving cowls worked by mechanical means, are all good if properly arranged.

There are two general systems of ventilation by

mechanical means—(*a*) the vacuum or extraction, and (*b*) the plenum or injection. For public buildings subjected to abnormal conditions, where the ventilation requires to be uniform and under control, these are the only reliable systems. For a perfect system it is necessary to have not only an outlet, but also a proper inlet, and for perfect working all windows and doors kept closed. When the doors are opened, especially if these be external doors, there is a partial disarrangement of the air currents; this defect may be reduced by having double doors to form air locks, or revolving doors as described on page 567.

(*a*) In the extraction method, as illustrated in figures 657 and 658, air inlets are formed, discharging fresh air into the rooms at a height of from 4 to 6 feet through Tobin tubes, and the outlet is arranged within a foot of the ceiling on the opposite side of the room from which the air enters. The air, after traversing the room, is drawn through the outlet, usually by a fan driven by mechanical means, and conducted to the roof and discharged above the highest level, preferably through a ventilating flèche.

Frequently a coil of steam or hot water pipes is arranged in the inlets, the fresh air thus being heated before entering the rooms. For efficiency by this method the outlet should be arranged in one angle of the room, and there should be an inlet at each of the remaining three angles.

(*b*) By the plenum system, as illustrated in figures 659 and 661, the air is drawn into a specially constructed chamber by means of a large fan fixed in a partition which divides this chamber. The air on entering should be filtered to remove all mechanical impurities. This is often accomplished by placing a water screen, *i.e.*, fine gauze screen, down which water is caused to trickle, which arrests and carries away all such impurities. On the further side of the fan two chambers are arranged, one containing coils of steam or hot water pipes to maintain a temperature in that chamber

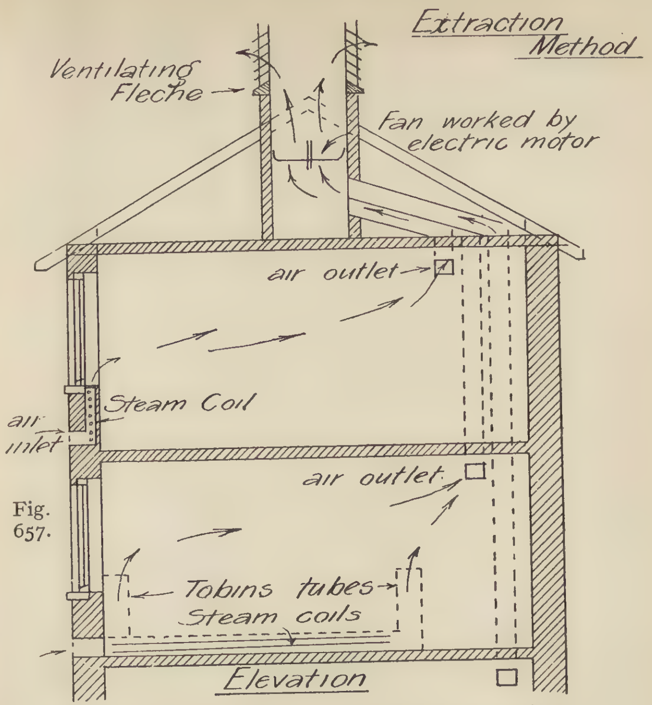


Fig. 657.

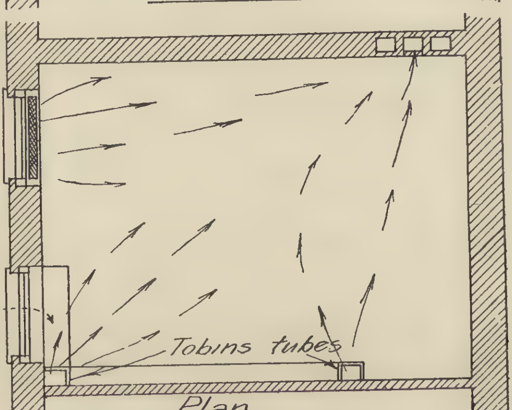


Fig. 658.

of about 160° Fahr., and beneath this a cold chamber. The air passing through the fan is forced into the hot or partially into the hot and cold chambers, from which main ducts are charged, one with hot and the other with cold fresh air. From the main ducts, hot and cold flues are conducted to each room, and are caused to discharge at a height of 1 foot from the ceiling line. The temperature of the room may be regulated by means of flaps, with which either the hot or cold ducts may be closed or regulated. The outlet is arranged at the floor level, directly beneath the inlet, through which the vitiated air is conveyed, preferably to the highest part of the building, and discharged as before described. It is claimed for this system that the temperature is more equable in all parts of the room, consequently the vitiated air, which at similar temperatures is usually heavier than ordinary atmosphere, gravitates to the lower part of the room, and the outlet is thus provided at that point at which the noxious gases under that condition tend to accumulate.

If either a stationary or a revolving cowl is used its efficiency is of little value when there is no wind or movement of the external atmosphere. And, on the contrary, excessive draughts in the rooms are caused when the external air is travelling at great speed. And again, fixed methods of ventilation cannot possibly be equally suitable for winter and summer seasons.

Stationary cowls are useful for preventing down-draughts. A simple pipe with a conical cover is less expensive and sometimes as effective as the more elaborate and costly stationary cowls.

Sectional Area of Ventilating Openings.—Ordinary atmospheric air contains ·04 per cent. of CO_2, that is, there are 2 parts of CO_2 in every 5,000 parts of air, and this quantity may be raised to ·06 per cent., or 3 parts in 5,000 without causing serious injury to health.

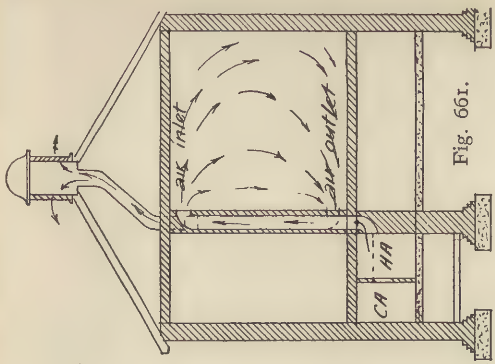


Fig. 661.

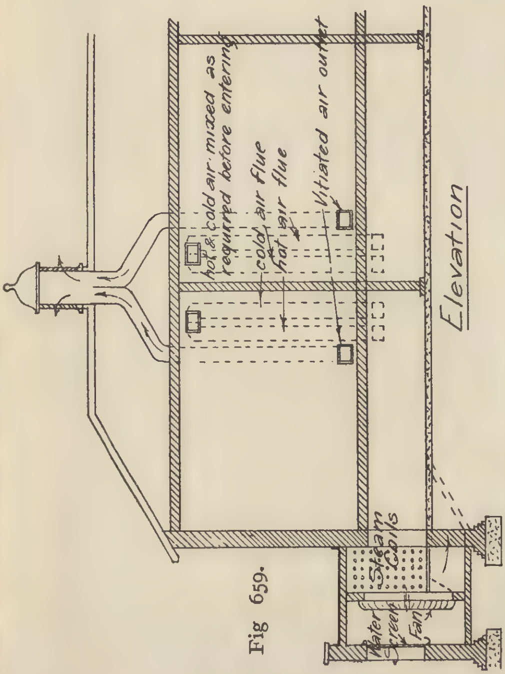


Fig 659.

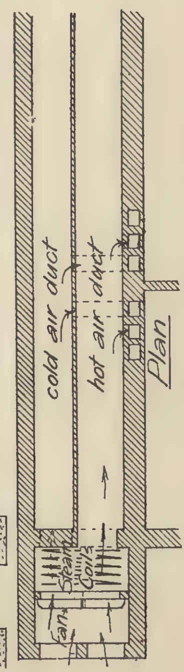


Fig. 660.

An adult gives off ·6 cubic feet of CO_2 in one hour, therefore he vitiates the air to the extent of $\frac{6}{10}$ of 5,000, or 3,000 cubic feet of air hourly.

Sick people vitiate $\frac{1}{3}$ more air than healthy adults.

Children vitiate $\frac{2}{3}$ the quantity of air vitiated by healthy adults.

A man at work vitiates 6,000 cubic feet of air per hour.

A horse vitiates 2,450 cubic feet of air per hour.

One foot of gas burnt per hour vitiates 1,800 cubic feet of air per hour.

A room containing 424 cubic feet can have the air changed four times in an hour without causing an unpleasant draught, but six times per hour is considered the maximum change permissible, as a higher speed than that would create offensive draughts.

Air increases ·002 of its volume for every increase in temperature of 1° Fahr., and the velocity of ascent may be calculated by the well-known Kinematical formula:— $\sqrt{2gh} = 8\sqrt{h}$ per second, and $3{,}600 \times 8\sqrt{h}$ per hour (32 feet per second being taken as the value of g), $h = Ht \times {\cdot}002$ where H equals the height of the column of heated air above the level of the fresh air inlet, and t = the excess in degrees Fahr. of heated air over the incoming cold air.

$$\therefore \text{Velocity per hour} = 3{,}600 \times 8\sqrt{h} = 28{,}800\sqrt{h} = 28{,}800\sqrt{Ht \times {\cdot}002}$$
$$= 28{,}800 \times {\cdot}0447\sqrt{Ht} = 1{,}296\sqrt{Ht} \text{ nearly.}$$

$$x - f = \frac{D}{9\sqrt{Ht}}$$

If x = total area in inches of required outlet shafts, D = total cubic feet of fresh air to be supplied by inlets; f = allowance for friction generally taken at $\frac{x}{4}$ to $\frac{x}{2}$, V = velocity of ascent of heated column in feet per hour, then

$$x - f = 144\frac{D}{V}$$

The right hand side is multiplied by 144 as the answer is to be in square inches, and $\frac{D}{V}$ would otherwise be in terms of super feet.

The sectional area of outlets may be obtained by the following formula :—

$$x - f = \frac{144\ D}{1{,}296\sqrt{Ht}} = \frac{D}{9\sqrt{Ht}} \text{ nearly.}$$

In practice inlets are usually made $1\frac{1}{2}$ times the area of the outlets.

Exhaust Shafts.—Figures 128 to 131 show two of the three usual methods of constructing exhaust shafts to carry away vitiated air.

(1) By mica flap outlets into smoke flues, the heated upward current of the smoke flue exhausts the foul air out of the room. The mica flaps close by any down-draught, and thus prevent smoke entering the room.

The disadvantage of this method is, that the valves make a noise which, at times, is irritating; they also get out of order by becoming covered with soot at the edges, and smoke then enters the room. If, however, these details are not considered as being serious objections, as when fixed in factories or workshops, this method may be claimed as being effective. Figures 128 and 129 show this method.

(2) By one common exhaust shaft with inlets from each room. This method is generally considered objectionable, as the shaft acts at times as a conductor of smells from the lower to the upper floors.

(3) By a special air flue from each room, as shown in figures 130 and 131, and which overcomes the objections to the two former methods, although the air would not in this case be so rapidly changed as by the first.

Warmed Air.—In the winter time it is better to warm the air before it is conducted into a room.

The Galton method of ventilating rooms is to warm the fresh air as it enters, by passing it through channels behind the fireplaces, and discharging it into the room about 8 feet above the floor level, as shown in figure 662. This

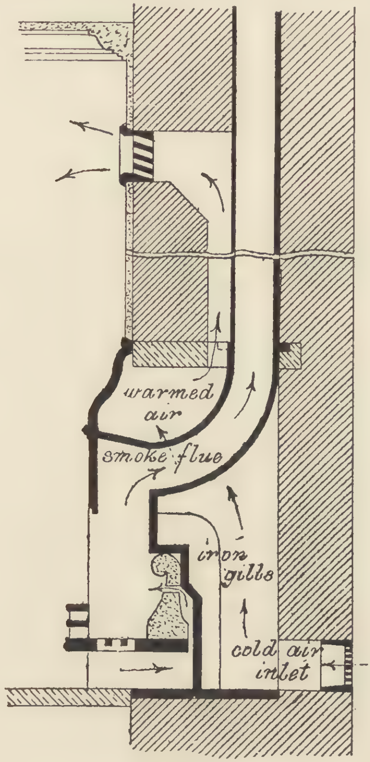


Fig. 662.

method is effective for large rooms where cold as well as warm air inlets are provided for supplying the required quantity. In another adaptation of this principle the warmed air is discharged immediately above the fireplace, with a sliding valve over the aperture to regulate the

supply, as shown in figure 663. There is a liability in both of these systems, especially when fixed in small rooms, of the air being overheated and rendered injurious to health. But this liability is reduced if the air-inlet damper is properly regulated.

The air in living rooms is best when warmed by coming

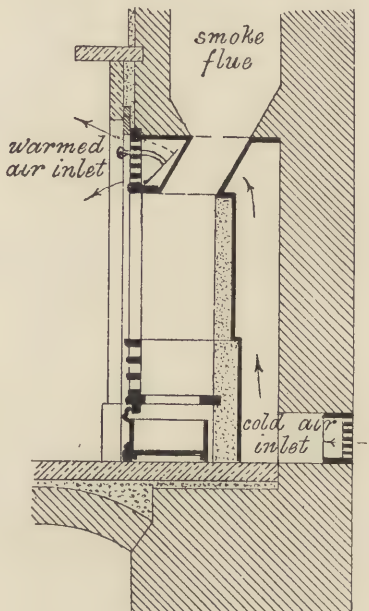


Fig. 663.

into contact with objects heated by the thermal rays from an open fire.

All stoves should be so designed as to give off the maximum quantity of radiant heat, to ensure the perfect combustion of the fuel, to require a minimum of stoking and fuelling, to burn with safety, and to create air currents

sufficient to carry off the products of the respiration of the people in the room.

Those stoves which burn on the slow-combustion principle most closely satisfy these conditions, and are suitable for bed and sick rooms.

Gas Burners.—The CO_2 and watery vapour given off by gas burners should be carried away by a funnel and tube arrangement, connected to a flue, as shown in figure 664, or continued through an outside wall into the external air, with

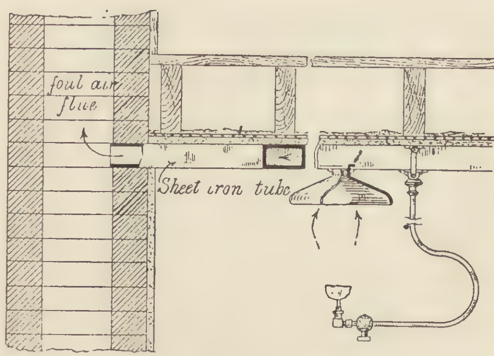


Fig. 664.

a wind guard on the outer end to prevent the gas being extinguished by a blow back.

Fresh Air Inlets to Rooms.—Fresh air can be introduced into rooms, by making the inside sash bead on the sill $1\frac{1}{4}$ in. by 4 in., as shown in figure 912, *Elementary Course of Building Construction and Drawing*, and opening the lower sash so that the bottom rail does not come above the level of the deep sash bead; there will then be an open space between the meeting rails of the sashes, through which the air will enter the room in a vertical direction.

Provision has been made in large public buildings for the introduction of fresh air at the soffits of the window

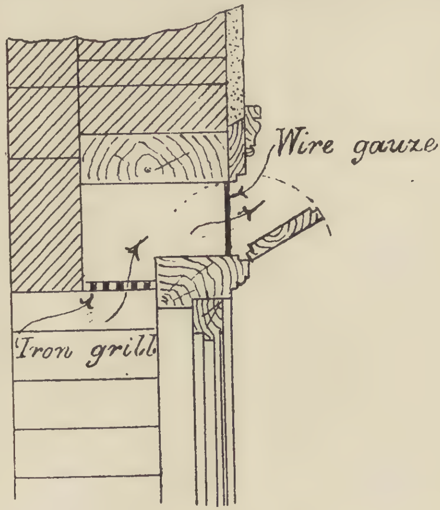


Fig. 665.

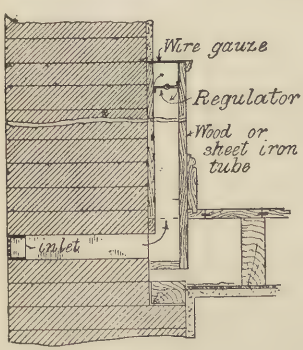


Fig. 666.

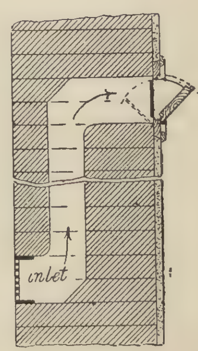


Fig. 667.

openings, as shown in figure 665. The internal architrave linings are framed with a hinged flap to regulate the supply.

Tobin's Tubes.—Fresh air is frequently introduced into rooms through vertical tubes which have hinged or rotating flap valves inside to shut off the current when it is desired to do so. The tubes should have an opening at the base for the removal of dust, and should discharge the air into the room about 6 feet above the floor level. Figure 666 shows a channel through the outer wall, such channel being connected to a wood casing fixed vertically. The incoming air is discharged in a vertical direction above the height of an average person. Sometimes the casings are made of zinc. By another method the air inlet channel is made of glazed stoneware pipes built in the walls. The external orifice is covered by a grating, and the admission of air is regulated by a hinged flap as in figure 667. The latter figure also shows an air channel constructed in the thickness of the wall.

In all cases it is necessary to make provisions for carrying off the air which may have become vitiated in any way. Ventilation is also necessary for carrying off the products of combustion which pass from the bodies of all human beings and warm-blooded animals, or are produced by the combustion of either gaseous or other fuel.

The Model Bye-Laws contain the following regulations:—

Any person who shall erect a new building shall not construct any chimney or flue of such building so as to make or leave in such chimney or flue any opening for the insertion of any ventilating valve, or for any other purpose, unless such opening be at least 9 *inches* distant from any timber, or other combustible substance.

Every person who shall erect a new domestic building shall cause every habitable room of such building which is without a fireplace and a flue properly constructed and properly connected with such fireplace, to be provided with special and adequate means of ventilation, by a sufficient aperture, or air shaft, which shall provide an unobstructed sectional area of *one hundred square inches* at the least.

Every person who shall erect a new public building shall cause such building to be provided with adequate means of ventilation.

CHAPTER XVII.

ELECTRIC BELLS AND LIGHTING.

Electric Bells.—The system of bells worked by the electric current, as illustrated in figures 668 to 671, consists of a battery, bell-pushes or pulls, and indicators connected by wires in such manner that a closed circuit may be formed at any time by pressing the push or using the pull. The battery known as the "Leclanché," where the electric current is generated, consists of a glass jar in which two poles, one zinc and the other of carbon, are immersed in an *exciting fluid.* The zinc and carbon terminals are connected to the other instruments by copper wires which convey the electric fluid from the battery when the circuit is complete.

The electric bell is placed in some convenient position in the circuit and is supplied with two screw terminals with which to make connection with the wires. Then the action is as follows: The current flows through the terminal A, and through the coils of the electro-magnet E; the latter is connected to an armature, to which the hammer of the bell is fixed. The armature is connected to the frame by a spring which is brought into contact with a screw contact point, which is in turn connected with a terminal which is secured to the main circuit. When the circuit is made the current flows through the electro-magnets round the frame and spring to the terminal; in passing along the coils the temporary magnet is magnetized and exerts an attraction upon the armature sufficient to overcome the

resistance of the spring, the armature is thus brought into contact with the magnet, but in so doing severs its connection with the contact point; the current is thereby broken, the magnet becomes de-magnetized and ceases to have any attraction for the armature, which is instantly drawn back to its original position by the spring, and again forms a closed circuit; the magnet thereby becomes re-magnetized and the process is repeated, the hammer striking the bell each time the armature is drawn to the magnet. Pushes are arranged at points in the circuit, from which, under normal conditions, the signal is to be made. Contact is obtained by pressing a push, which closes the circuit and rings the bell when desired.

At one point in the circuit, usually close to the bell, an indicator is fixed with as many signals as there are pushes, from each push the wire is taken to the indicator, and so makes connection to an electro-magnet. From thence it usually passes by a terminal joined to the main wire, which conveys the current from any push to the bell. When contact is made at any push the current flows round the coil of the electro-magnet in the indicator which, upon thus becoming magnetized, attracts an armature, which in its movement releases the signal, which falls by gravity. The signal is replaced by hand or by pushing a lever.

Electric Lighting.—Electricity for lighting purposes may be obtained in many places from a central station, but it is frequently necessary and more economical in many establishments to generate electric current on the spot. In the latter case some form of prime mover, such as a steam or gas engine, is necessary, the mechanical energy of which is converted into electrical energy by a dynamo which consists of field magnets, between the parts of which an armature is caused to revolve at a high velocity. The wires on this armature cut through the lines of force

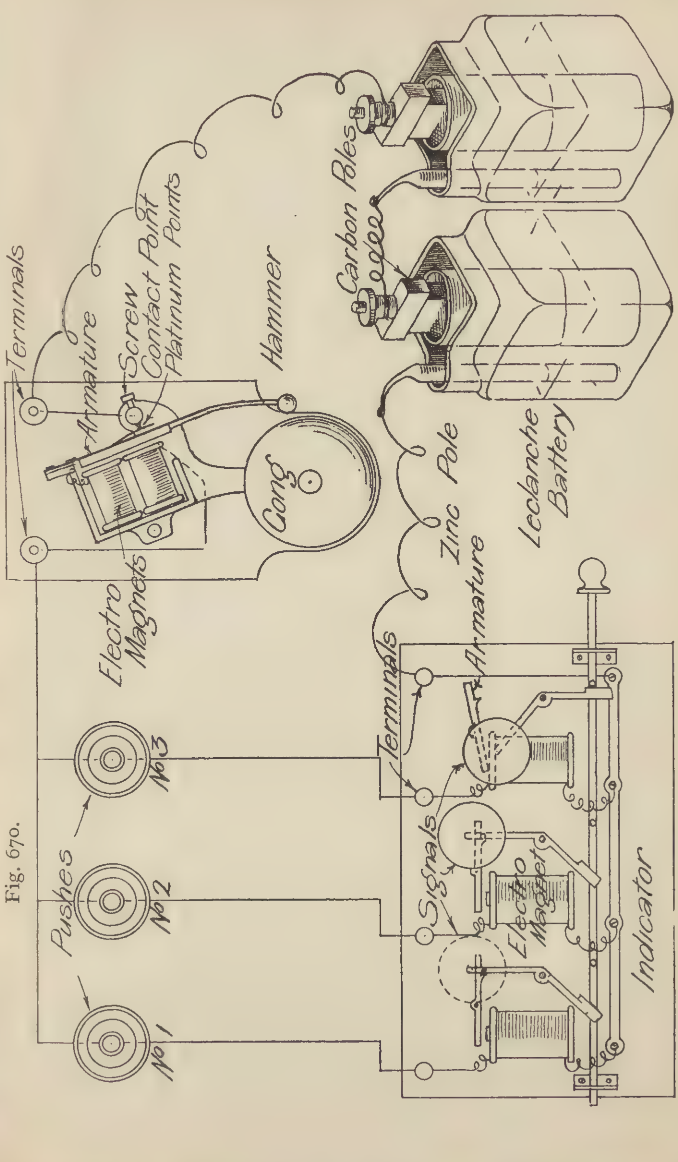


Fig. 668.

Fig. 669.

Fig. 670.

Fig. 671.

produced between the poles of the magnet, and in so doing generate an alternating electric current. Brushes are provided for leading the current away from two insulated rings on the shaft. If a direct current is required a commutator replaces the two rings and brushes touch at the ends of a diameter of the commutator. From the brushes wires lead to terminals connected with the main circuit lamps, etc., and others to the field magnet coils for the purpose of exciting them. The user of the machine has therefore to lead a conductor from one terminal to the lamps, etc., and a return conductor from the lamps to the second terminal of the machine. The two cables that are connected with the dynamo are now equivalent to the cables that are brought into a building from a company's mains. In some cases the company puts a transformer into a convenient part of the building and supplies electrical energy through it; by this device a company can economically serve a very large district. They use in the roads and streets a higher pressure than is allowed by the Board of Trade inside ordinary buildings, and this higher pressure is reduced to the safe allowable limit by the transformer; at the same time it increases the strength of the current, so that the power given out by it is only 3 or 4 per cent. less than that taken in.

If the cables are taken from a company it will be necessary to have a meter, but before the current passes into the meter there should be a main switch and a fuse. The latter is an apparatus for preventing the current rising beyond the maximum safe value for the house wires. From the meter the wires are taken to a main fuse and distributing switchboard, from which the wires pass to different parts of the house and from whence all the different sections can be controlled. Where there are many points on the different sections it is usual to have a distributing board for each section. Electricity is thus conveyed along

the cables or wires, for lighting, heating and cooking purposes, by attaching the necessary apparatus for any of these objects. In usual practice the lamps used for lighting purposes are the arc and the incandescent, the former being used for illuminating large areas and the latter for internal requirements.

The direct current is preferable for the arc lights and also for motors. For incandescent lights and cooking it is immaterial if the current is direct or alternating.

Figure 672 shows a diagram of a house with a typical system of wiring and the necessary apparatus.

Supposing it to be necessary to fit up an electric light installation in any building, the following are the requirements :—

(*a*) Supposing the current is to be generated on the premises, 1st, a steam, gas, hot air, or oil engine to produce the mechanical energy to work the dynamo; 2ndly, a dynamo to convert the mechanical into electrical energy; 3rdly, accumulators to store the current that would be in excess of that which is immediately required; 4thly, a main fuse; 5th, main switch; and 6th, a meter.

(*b*) Supposing the current is to be obtained from a company's mains, all the apparatus, which consists sometimes of a transformer, main fuse, main switch, and a meter, up to the main distributing board, is supplied by the company. From this point the arrangements and fittings would be similar, whether the current is obtained from a company or generated in the building.

It will be found useful to be acquainted with the following units :—

Ohm = Unit of resistance, and is the resistance offered by a thread or column of pure distilled mercury 106·3 centimetres in length, 1 square millimetre in cross section, at a temperature of 0° C.

Volt = Unit of electromotive force, and is nearly equal to the E.M.F. of a Daniell's cell.

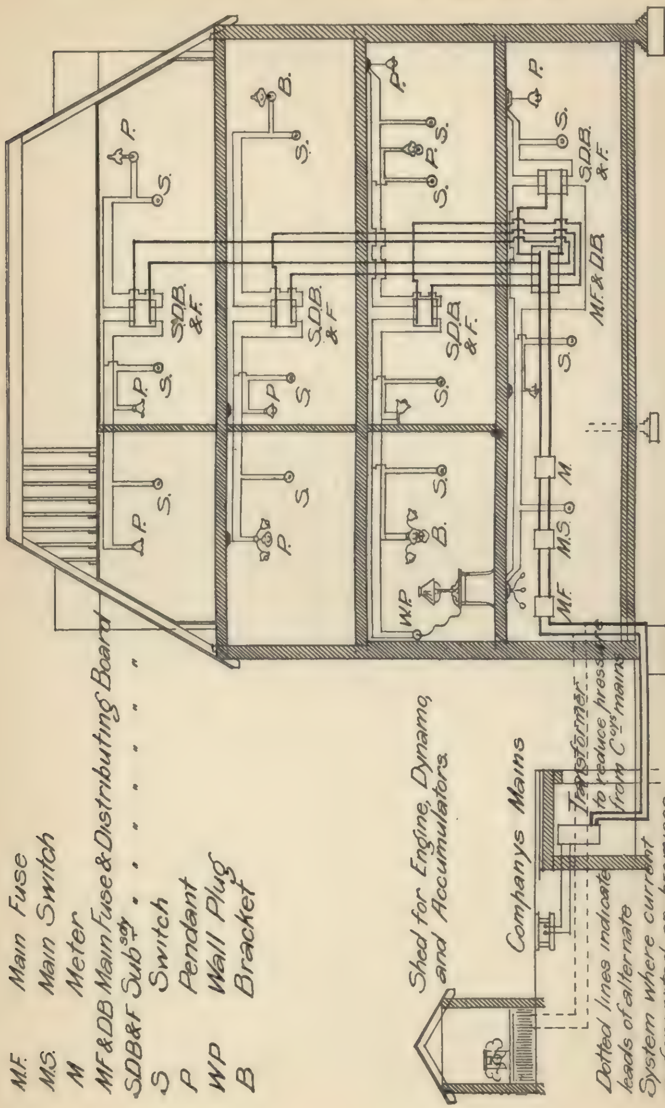

M.F. Main Fuse
M.S. Main Switch
M Meter
MF & DB Main Fuse & Distributing Board
S.D.B.& F Sub^sdy " " " "
S Switch
P Pendant
WP Wall Plug
B Bracket
Shed for Engine, Dynamo and Accumulators
Companys Mains
Transformer to reduce pressure from C^oys mains
Dotted lines indicate leads of alternate System where current is generated on premises
S.D.B. & F.
MF & DB
M.F.
M.S.
M.
W.P.
P.
S.
B.

Fig. 672.

Ampère = Unit of current, and is the current given by an E.M.F. of 1 volt through a resistance of 1 ohm.

Coulomb = Unit of electrical energy = Current of 1 ampère maintained for 1 second.

Joule = Unit of heat, and is the amount of heat produced in 1 second by a current of 1 ampère flowing through a resistance of 1 ohm.

Watt = Unit of power, and is the power due to a current of 1 ampère acting through a difference of potential of 1 volt.

Kilowatt = 1000 watts.

Board of Trade unit = Kilowatt hour = 1000 watt hours = 1000 ampère volt hours.

EXERCISES.

MATERIALS.

No.	Question.	No.	Question.	No.	Question.	No.	Question.
1	1	13	102	25	154	37	199
2	13	14	123	26	182	38	217
3	15	15	124	27	187	39	218
4	32	16	125	28	188	40	219
5	36	17	146	29	189	41	220
6	40	18	147	30	192	42	221
7	49	19	148	31	193	43	222
8	50	20	149	32	194	44	223
9	71	21	150	33	195	45	224
10	89	22	151	34	196	46	225
11	90	23	152	35	197	47	226
12	99	24	153	36	198	..	..

FOUNDATIONS.

1	23	3	78	5	101	7	168
2	55	4	95	6	167	8	..

BRICKWORK.

1	54	5	81	9	141	13	216
2	72	6	109	10	168	14	..
3	79	7	114	11	183	15	..
4	80	8	131	12	185	..	..

STABILITY OF WALLS AND TALL CHIMNEYS.

1	51	2	136	3	250	4	251

MASONRY.

1	64	4	82	7	120	10	212
2	42	5	98	8	169	..	..
3	58	6	109	9	191	..	..

CARPENTRY.

1	83	5	141	9	190	13	238
2	97	6	175	10	211	14	254
3	103	7	176	11	214	15	259
4	129	8	186	12	216	..	..

PILLARS.

1	106	3	184	5	249		
2	173	4	216	..	..		

GRAPHIC STATICS.

1	4	4	57	7	126	10	232
2	38	5	94	8	127	11	253
3	52	6	118	9	230	12	..

GIRDERS, BEAMS, ETC.

1	2	8	93	15	177	22	228
2	3	9	110	16	178	23	229
3	16	10	119	17	179	24	231
4	18	11	127	18	180	25	236
5	37	12	128	19	185	26	252
6	53	13	143	20	216	..	..
7	86	14	144	21	227	..	..

FLOORS.

1	108	2	121	3	182	4	203

FERRO-CONCRETE CONSTRUCTION.

1	104	2	139	3	174	4	213

WOOD ROOFS.

1	92	3	181	4	258	5	
2	96	..	..	..	..	..	

IRON AND STEEL ROOFS.

1	57	3	132	5	172		
2	94	4	170	6	233		

ROOF COVERINGS.

1	9	5	133	8	170	11	255
2	46	6	137	9	171	12	256
3	64	7	150	10	215	13	257
4	71	..	..	..	..	..	..

JOINERY.

1	10	5	48	9	107	13	186
2	21	6	67	10	115	14	211
3	22	7	84	11	116	15	214
4	39	8	85	12	133	16	260

SANITATION, HEATING AND VENTILATION.

1	20	9	113	17	158	25	205
2	43	10	122	18	159	26	235
3	56	11	130	19	160	27	243
4	65	12	140	20	161	28	244
5	72	13	142	21	200	29	245
6	88	14	155	22	201	30	246
7	91	15	156	23	202	31	247
8	105	16	157	24	204	32	248

ARCHITECTURE.

1	25	3	60	5		7	
2	26	4	61	6		8	

SPECIFICATIONS, QUANTITIES, ESTIMATING AND PROFESSIONAL PRACTICE.

1	5	8	33	15	137	22	207
2	19	9	41	16	162	23	208
3	27	10	62	17	163	24	209
4	28	11	63	18	164	25	210
5	29	12	64	19	165	26	..
6	30	13	68	20	166	27	..
7	31	14	69	21	206	28	..

DESIGN.

1	35	4	74 to 76	6	111	8	145
2	66	5	105	7	138	9	..
3	70	..	..	..	..	..	..

ELECTRIC BELLS AND LIGHTING, AND MISCELLANEOUS.

1	17	4	135	7	239	10	..
2	85	5	234	8	..	11	..
3	87	6	237	9	..	12	..

IRONMONGERY, PLASTERING, INTERNAL PLUMBING AND PAINTING.

1	7	4	26	7	62	10	..
2	8	5	11	8	117	11	..
3	44	6	14	9	45	12	..

DRAWING.

1	12	4	34	7	77	10	134
2	24	5	47	8	100	11	..
3	28	6	59	9	112	12	..

APPENDIX.

BOARD OF EDUCATION SYLLABUS.

(Published September 3rd, 1906.)

SUBJECT III.

BUILDING CONSTRUCTION AND DRAWING.

THE instruction given should be so arranged that by the time the Student finishes his course of study, he should have acquired a knowledge of building materials, plant and construction sufficient for the work upon which he is likely to be engaged. That he may be able to make free use of this knowledge in practice, he must also be a good draughtsman; good drawing is an essential part of the course, but it must always be borne in mind that drawing is a *means* and not an end in itself; drawings of work to be carried out should be such as to give full information and exact guidance to workmen who may have to use them. In the higher stages of the subject students should acquire proficiency in making finished drawings as well as what may be called descriptive and explanatory drawings.

A larger number of questions will be set in the examination papers than the candidate will be allowed to attempt, so that he may have some range of selection of questions which bear upon branches to which he has given special attention.

Compulsory questions may be set at the examinations.

It should be seen that candidates are fairly provided with pens, ink, pencils, and drawing instruments (including tee and set squares, drawing boards, Indian ink, &c.) when they present themselves for the examination. The use in examination of the ordinary box-wood, ivory, or paper scales and protractors, and slide rules is permitted. Tables will be supplied to candidates in Stage III., and Honours to assist them in calculation.

Stage I. (Elementary).

In Stage I., the drawing exercises should not extend beyond descriptive and explanatory drawing, but they should aim at cultivating a fair degree of skill in pencil drawings. All lines should be neat and clear. Students who are quick in executing their pencil drawings should practise making ink tracings with clear lettering and figuring.

All students should practise freehand drawing of details, so that they may be able readily to make a neat dimensioned sketch from which a drawing to scale might afterwards be prepared or which may itself be sufficient for purposes of explanation. The use of squared paper may be introduced with advantage in exercises of this kind.

The course should include elementary instruction, with reference to the various materials used in building. Each group of materials should be taken up in the class as introductory to a series of drawing exercises, illustrating their use in buildings so far as suitable for discussion in a first year's course. There would fall to be considered in this way: the nature and properties of sand, lime, and cement; the composition of mortar or concrete and its application in floors, walls, &c.; the properties of bricks, stones, tiles, and slates; the various kinds of timber in ordinary use; the constituents of cast-iron, wrought-iron, and steel, and the essential or characteristic differences of their properties.

Instruction should be given as to foundations in ordinary soils, footings for walls of moderate height; the construction of simple scaffolding; the various bonds of brickwork in plain walling, flues, arches, and fire-places; varieties of simple masonry such as rubble and ashlar walling and the plain masons' work on sills, reveals, &c.; plain carpentry in floor joists, stud partitions, ordinary roofs of span not exceeding that for a King-post truss; firrings of flats; simple joiners' work in floor laying, skirtings, deal-cased frames and double-hung sashes, and solid frames for simple casements, panelled doors and jamb linings, door frames and ledged and braced doors; ordinary plastering on walls, partitions, and ceilings, and the composition of the various coats; slating, including the dressing, cutting, and nailing of the slates; plain tiling and pan tiling and the various

methods of hanging the tiles, and the treatment of valleys, hips, ridges, and eaves ; roof plumbing, including the laying of flats with rolls, drips, &c., lead gutters, and flashings; simple glazing. Students should also be taught how to draw the sections of rolled joists, channels, angles and tees.

In all these subjects practical examples of the materials used and the various operations of dealing with them should be brought before the student, either in the class room or elsewhere ; in as many cases as possible, he ought actually to see and handle full size examples of everything in which he is being instructed theoretically. He should also familiarize himself with the nature and use of all the tools used in elementary building operations. Students should lose no opportunity to inspect any building operations going on in their locality. Every student ought to examine in detail the structure of the houses in which he lives and works and attends classes.

STAGE II. (ADVANCED).

Before proceeding to Stage II., Students should have a good knowledge of the subjects included in the Syllabus for a Preliminary Course for Trade Students, as well as of those subjects included in the above Syllabus for Stage I.

The Course of Instruction in this Stage should cover a more advanced knowledge of all the subjects enumerated for Stage I., together with simple exercises in calculating quantities of materials, not such calculations as a Quantity Surveyor would make, but such as would fall to be made by a Foreman of Works who has to order sufficient materials for the amount of work which he knows has to be done.

The class lessons and drawing practice should include the following subjects: Excavation in various kinds of soils, including strutting and planking, concrete foundations for walls and piers, the use of damp courses and the materials employed for them; gauged brickwork; hollow walls and the various methods of bonding them together ; junctions of walls of various thicknesses and at different angles : chimney breasts and flues ; irregular bonds ; fireproof construction in floors and roofs; the best known building stones, their quarrying, bedding, cutting and dressing; characteristics of timber, its conversion and seasoning. Attention should be

given to the increasing use of machinery in treating timber for carpenters' and joiners' work; advanced carpentry and joinery; ordinary forms of staircase construction with close strings and bent strings; two and three-light windows with cased frames, and hung sashes, and also with solid frames, mullions and transoms and casements, outside doors with bolection mouldings, sash doors and the finishings of door and window openings; finishing in eaves, hips, ridges, &c.; the nature, qualities and weights of various kinds of slates; elementary drainage; the laying and jointing of glazed stoneware pipes; advanced constructional plumbers' work, including cold water supply to cisterns, and the position of the same in a house, baths, sinks, water-closets and their connections, waste pipes, soil pipes, ventilation pipes, &c.; scaffolding for large buildings, shoring, strutting, needling, and under-pinning; centring for arches up to 15 feet span; the general principles of loaded beams; bending moments due to concentrated and distributed loads; the use of the triangle and polygon of forces in order to practically determine the resultant force in direction and magnitude, and to resolve such a resultant into its component forces; the determination of the stresses in simple braced structures; elementary exercises in the calculation of strength of materials.

STAGE III. (OR HONOURS, PART I.).

The Course of instruction should include the consideration of buildings of all kinds and sizes. In the examination the candidate will be expected to show that he has a fair knowledge of the principles of Physical Science as illustrated in relation to building construction. He should be able to design simple roof trusses and beams, and to draw their stress diagrams; he should know the elements of the theory of arches, how to provide for the stresses in various parts of a building, and the methods of inspecting and testing cement, timber, iron and steel, and the use of formulæ.

In the various sections of the Course exercises in calculating quantities of materials should be continued as in the preceding Stage.

The class lessons and drawing practice should include the consideration of:—

Foundations—natural and artificial, upon land and under

water, damp sites and their treatment, brickwork, including all kinds of bonding, setting out bond in frontages, &c.

Terra cotta and artificial stone; their manufacture and uses.

Principles of sanitation; drains, traps, gulleys, disconnecting chambers, sewers, their ventilation and drain connections, iron drains. Drain testing and ventilation.

Masonry. Character of various stones used in building and localities where found, how to test for quality and bed, fitness of various stones for different atmospheres, weight generally, and approximate strength; stone stairs, composite walls, arches.

More detailed knowledge of scaffolding, including gantries, elaborate centring, framing for concrete walls and modern methods of hoisting materials, roofing up to 60 feet span. Timber: its seasoning, diseases, cause of decay, and means of preserving it. Roof timbering, open, hammer beam, and composite trusses. Modern iron trusses, including trussed purlins; all roof finishings, including slating, tiling, plumbing, &c., sky lights and lanterns. Wood stairs of all kinds, including handrailing.

Cast iron, wrought iron and steel, properties, uses, strength, weight and preservation. Iron and steel columns, stanchions and girders, including riveting, bolting, &c. The calculation of bending moments and shearing stresses.

Ventilation and heating; hot water supply; provisions for gas and electric supply, in so far as these may affect the structure of the building; water supply; lightning conductors; preservation of timber, various kinds of glass and glazing; plastering in all its branches.

Attention should be specially directed to the increasing use of skeleton construction in steel, and to ferro-concrete construction.

Honours.

No candidate will be credited with a success in Honours who has not obtained a previous success in Stage III., or in Honours of the same subject under previous Regulations, and who does not qualify in the Board's examination in Architecture. The qualification in Architecture need not be obtained in the same year as that in the Honours examination in Building Construction and Drawing.

The Examiners will have in mind in setting the questions the actual practice of architects in designing buildings, and in their guidance of assistants and clerks of works, to ensure that orders will be properly carried out, the dealings with contractors, and also the actual erections of buildings and carrying out of building operations. Candidates will be asked to make sketch designs and to give instructions to draughtsmen for careful scale drawings and specifications. The questions may deal with any part of the subject and with any kind of building, and may require a knowledge of any materials or construction in use in good practice.

Those candidates whose answering of the paper is sufficiently satisfactory will be summoned to South Kensington or some other centre for a practical examination. This further examination will last for two or more days; the time will not exceed seven hours each day. Candidates will be asked to design a building suitable for a definite purpose, and they will be called upon to give such plans, elevations, and sections, and such details and notes for a specification, as shall be required by the Examiner. An estimate of cost may also be demanded.

Intimation concerning the general nature of the building to be designed will be sent in advance to candidates, together with the notice to attend for this second part of the examination.

For this practical examination candidates must provide T squares, set squares, drawing instruments, ink, and colours. Drawing paper and drawing boards will be supplied by the Board of Education.

No candidate can be classed in Honours who is not successful in the practical examination.

EXAMINATION PAPERS

OF THE

BOARD OF EDUCATION, SOUTH KENSINGTON, LONDON.

SUBJECT III. BUILDING CONSTRUCTION AND DRAWING.

STAGE 2, STAGE 3, AND HONOURS.

GENERAL INSTRUCTIONS.

IF THE RULES ARE NOT ATTENDED TO, YOUR PAPER WILL BE CANCELLED.

Immediately before the Examination commences, the following

REGULATIONS ARE TO BE READ TO THE CANDIDATES.

Before commencing your work, you are required to fill up the numbered slip which is attached to the blank examination paper.

You may not have with you any books, notes, or paper other than that supplied to you for use at this examination.

You are not allowed to write, draw, or calculate on your paper of questions.

You must not, under any circumstances whatever, speak to or communicate with another candidate. Those superintending the examination are not at liberty to give any explanation bearing upon the paper.

You must remain seated until your papers have been collected, and then quietly leave the examination room. No candidate will be allowed to leave before the expiration of one hour from the commencement of the examination, and none can be re-admitted after having once left the room.

All papers, not previously given up, will be collected at 10 o'clock.

If any of you break any of these regulations, or use any unfair means, you will be expelled, and your paper cancelled.

Before commencing your work, you must carefully read the following instructions :—

You may take Stage 2, or Stage 3, or, if eligible, Honours, but you must confine yourself to one of them.

The questions may be answered in any order, but each answer must be clearly marked with the number of the question to which it refers.

A table of logarithms and functions of angles and useful constants is supplied for each candidate on whose behalf application has been made for a paper in Stage 2, Stage 3, or in Honours.

Drawings must be made on the single sheet of drawing paper supplied, beginning on the side marked with your distinguishing number, which must face you at the right-hand top corner. *Sketches* may be made by hand on the squared paper attached to the drawing paper. Additional foolscap will, if necessary, be supplied to you by the Superintendents.

The tracing is to be drawn on the piece of tracing paper attached to the drawing paper.

Answers in writing must be as short and clearly stated as possible, and the references to drawings and sketches must be made absolutely clear by letters or numbers.

The value attached to each question is shown in brackets after the question. But a full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

Questions marked (*) have accompanying diagrams.

The examination in this subject lasts for four hours.

The numbers in brackets relate to the general numbering of all the questions printed in this volume, and are those referred to in the List of Exercises (pp. 688 to 691).

MAY, 1903.

SECOND STAGE OR ADVANCED.

INSTRUCTIONS.

Read the General Instructions on page 701.

You may not answer more than six questions.

The drawings in answer to questions 24, 27 (any drawing the candidate may think useful for 29) and 30 should be on the drawing paper; they may be in pencil. Written answers on squared paper (and foolscap) should be in ink. Additional foolscap may be obtained from the Superintendents of the examination.

[*The questions starred have an accompanying illustration.*]

(1.) 21. What is quicklime, and how is it produced? Use such terms as you think would be intelligible to a workman familiar with the handling of lime and plaster of Paris, and describe: (*a*) what happens when water is applied to quicklime; (*b*) what happens when plaster of Paris is mixed with water—to be used for casts: giving the best rational explanation you can of the actions? (24.)

(2.) 22. You have a special kind of timber from which to take flooring joists.

The formula

$$\triangle = k\,\frac{w\,L^4}{b\,d^3}$$

expresses a law, where $\triangle$ stands for the drop or deflection at the centre, w the load per unit of length, L the length between the supports or bearings, b the breadth or thickness, d the depth. Describe an experiment (using a piece of the timber and making use of bricks for load, etc.), by which you can determine k. (24.)

(See note to question 24.)

(3.) 23. Assuming that you have made the experiment of the previous question and that you have found k to be

·000000084 (the units being:—foot and hundredweight); what is the stress per unit of cross-sectional area on the outer fibres at the cross section of greatest bending moment:

$L = 20'$, $b = \frac{1'}{6}$, $\triangle = {}^{\cdot}05'$, $w = 1{\cdot}25$ cwt.? (36.)

(See note to question 24.)

(4.) *24. Draw the stress diagram for the roof truss loaded as shown. (29.)

(NOTE.—A candidate can obtain marks for not more than two of the three questions, Nos. 22, 23, and 24.)

(5.) 25. Answer only one of the following, (*a*) or (*b*):—

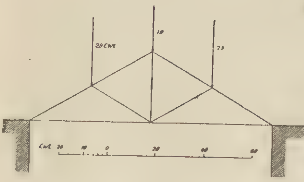
(*a*) Bricks ($9'' \times 4\frac{1}{4}'' \times 3''$) cost 35*s*. a thousand; Portland cement costs 3*s*. 6*d*. a bushel; sand costs $2\frac{1}{2}d$. a bushel (all as delivered on the works). What is the cost for these materials for a cubic yard of two-brick wall (mortar, 1 of cement to 3 of sand, joints to show $\frac{1}{2}''$ thick)? (21 bushels in a cubic yard.) (33.)

(*b*) Bricklayers' wages are 1*s*. an hour, attendants' wages 6*d*. an hour; for plain brick walling, 16 to 30 feet over ground, give a reasonable proportion between cost for bricklaying and cost for attendance. Including both items, what is a fair cost per cubic yard for workmanship? What other items of expenditure should be charged to the brickwork? Give reasons for your proportion and estimate. (33.)

(6.) 26. In towns where Ashlar masonry is common the lintels to window and door openings, though of excellent stone, are seen to be in very many cases broken across; explain the cause of this. How might this fracture of lintels be prevented? (24.)

(7.) 27. Draw (*a*) the elevation, (*b*) a vertical cross section at the centre, and (*c*) a half horizontal cross section (just over the grate) of a good register grate fireplace, to the

(24.)



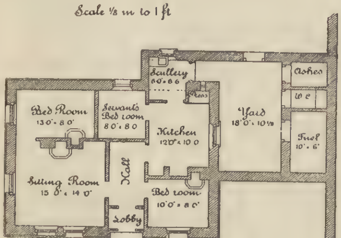
(28.)

(Honours, Part II.)

(63.65 70.)

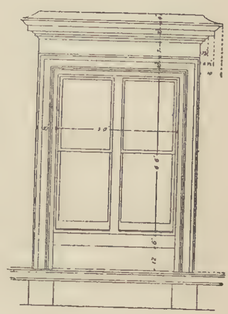
Front Elevation.

Scale 1/8 in to 1 ft



Ground Plan

(32.)



Elevation of a Window

scale of $\frac{1}{8}$. How is the fireblock back to be renewed? How is the chimney to be swept and the soot cleared away? (33.)

(8.) *28. A cornice of the cross section shown is to be formed round the ceiling of a room : describe the complete operations (omit the making of modillions and their attachment, also the finishing of the soffit) : describe the materials used : describe moulds, screeds, rules, and tools used, and modes of using them. How are the dentils made and attached? Describe the working of a mitre. (36.)

(9.) 29. A right circular cone roof, over a lantern, is 8′ in diameter at the eave, it is 3′ high (from base at eave to vertex), it is to be covered with copper plates in the manner of slating, they are trimmed and bent to fit on. The margin is 6″, the lap is 3″; the apex is finished with a conical cap of sheet copper, 8″ diameter at the base; the sheet copper weighs 3 lbs. per superficial foot; omitting nails, what is the total weight of copper on the roof? (33.)

(10.) 30. Draw carefully to the scale of $\frac{1}{8}$ the horizontal cross section of a fully-trimmed window, through one jamb and reveal. The wall is of stone, ashlar face; reveal 6″ deep; wall 2′ thick, battened (or stoothed). Show jamb-lining, three-faced architrave, folding shutters (window about 4′ wide), ground, lathing and plaster. Sketch to the scale of $\frac{1}{6}$, cross section through sash bottom rail, oak sill, and stone sill. If you adopt a water-bar explain how you prevent water passing inwards at the ends of the oak sill. (28.)

(11.) 31. Answer only one of the following, (*a*) or (*b*) :—

(*a*) Sheet lead which is repeatedly treated to sudden dashes of warm (or hot) water wrinkles permanently in a remarkable manner (seen when a scullery or pantry sink is, as is occasionally done, lined with sheet lead), explain this. (24.)

(*b*) Sketch neatly and clearly a longitudinal section of a good screw-down bib-cock. (24.)

(12.) *32. Trace neatly, in ink, the drawing shown, also the writing and figures. (The Indian ink should be sufficiently thick to give opaque lines suitable for photographic printing; the lines should be well defined, uniform in breadth, having firm, unbroken edges; they should neither stop short of nor go beyond the proper points.) (28.)

1903.

HONOURS—PART I.

Instructions.

Read the General Instructions on page 701.

You may not answer more than six questions, of which at least one must be selected from each of the first two divisions and two from the last. The tracing must be attempted.

Sketches and answers may be on the squared paper which is attached to the drawing paper. Additional foolscap may be obtained from the Superintendents of the examination.

The tracing should be drawn on the tracing paper attached to the drawing paper.

The drawings, in answer to questions 44 and 50, should be on the drawing paper; they may be in pencil.

Division I.

13.) 41. (*a*) Describe a lime-kiln—illustrate with sketches. Describe the preparation of limestone for burning. (*b*) Given—Ca 40, O 16, C 12; what weight of lime should result from a charge of 4 tons of limestone? The weight of limestone is made up of 3·424 tons of $Ca\ CO_3$ + ·4 ton of a substance not altered in weight by the burning, + ·176 ton of water which is driven off. (*c*) How many cwt. of coals (approximately) are required to burn 4 tons of limestone to lime? (51.)

(14.) 42. Describe exactly the manufacture of lead pipes for plumbers' work. Illustrate your description with sketches. (45.)

(15.) 43. Describe carefully the preparation of plaster of Paris. In what respects does plaster of Paris differ from the gypsum from which it is made? (45.)

DIVISION II.

(16.) *44. It is assumed that the girder shown may be separated into two determinate girders, placed side by side, and the load also divided and placed equally on the two girders. When thus loaded and stressed the two girders may be recombined without alteration in the stresses. On this supposition, find graphically the stresses in the members of the girder loaded as shown. (Full marks will be given for an accurate continuous diagram which will include all the joints between A and B.) (51.)

(17.) 45. The reservoir (for distribution) of the waterworks of a small town is a circular cylinder, 30 feet high and 20 feet in diameter. When the cylinder is full of water, what is the tensional stress in a ring of the cylinder 1 foot wide (or deep), whose centre line is at the height of 1 foot 6 inches from the bottom? What should be the thickness of iron plate to safely sustain this stress? (51.)

(18.) *46. A mild steel joist, of the cross section shown, rests horizontally on two supports, one at each end, having its web vertical; it is 40 feet long:—

(*a*) Given

$$\triangle = \frac{5}{384}\frac{W L^3}{E I}, \; E = 30{,}000{,}000 \text{ (lb.-in.)},$$

$$I = \frac{b\, d^3 - b_1\, d_1^{\,3}}{12},$$

find $\triangle$ in inches. (Rounded angles taken as not rounded; take the average thickness of flanges.)

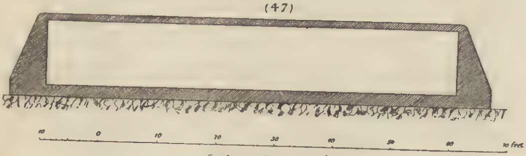
(*b*) What is the maximum stress in lbs. per square inch upon the steel at the cross section of greatest bending moment? (51.)

DIVISION III.

(19.) *47. The drawing shows a vertical section, through a diameter of a circular concrete and masonry reservoir; the

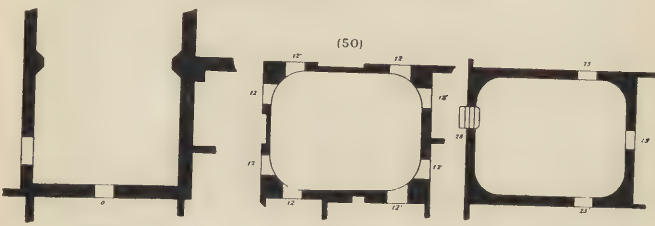
SUBJECT III. *(Honours. Part I.)*

(47)



Scale, (47) and (50)

(50)

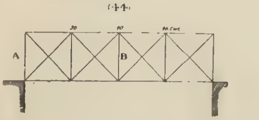


Ground *First Floor.* *Second Floor*

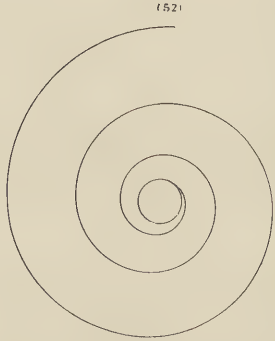
(46)

One eighth of full dim.

(44)



(52)



Ionic Volute.

flat cover is supported upon cast-iron pillars, 6 inches in diameter, metal $\frac{3}{4}$ inch thick; square flanges on their ends, 12 inches by 12 inches, $\frac{7}{8}$ inch thick (the pillars are not shown on the drawing, they are 34 in number). Find accurately (*a*) the quantity of masonry and concrete combined; (*b*) the quantity of water in gallons that the reservoir will hold when the water surface is within 6 inches of the roof; (*c*) the weight of iron in the pillars; (*d*) the quantity of surface to be floated and trowelled smooth; (*e*) draw up an estimate of the cost of this reservoir (omit standpipe, overflow, and washout; but include manhole and foot irons). (51.)

(20.) 48. Sketch to the scale of about $\frac{1}{8}$ a vertical section to show the parts of a first-class wash-down water-closet. Show the connexion with the soil-pipe: show the flushing tank and explain its parts and mechanism: show particularly the connexions of the porcelain with the metal piping. (51.)

(21.) 49. Give careful instructions; give dimensions; make sketches of parts; specify particularly the materials; for a good ordinary pattern house painters' ladder 30 feet long. How much should it cost? (45.)

(22.) *50. The drawings show the ground floor, and the first and second floors of a building and the doors opening into a central well; there is a third floor having 3 doors exactly over the three doors marked 25′ on the second-floor plan: design stairs and landings for these floors: the height of the third floor is 40 feet; winders are not allowed: it will be sufficient to show the risers of bottom steps and top steps at landings, etc., and to give the number of intermediate risers: landings should be marked distinctively with two diagonal lines. The heights, over ground, of the different floors are marked on the plans.—Ground floor 0′, first floor 12′, second floor 25′ and 28′ (the risers are shown from the 25′ level to 28′ level). (51.)

(23.) 51. (*a*) Sketch to the scale of $\frac{1}{8}$ the head and point of a 12″ × 12″ timber pile prepared for driving. (*b*) What do

you know of the pressure between the base of the monkey and the head of the pile after impact? (*c*) If a monkey weighing 8 cwt. falls 7 feet to the head of a pile and drives the pile 1 foot, what is the effective average pressure on the head of the pile during its motion? (*d*) If the pile is driven only a very short distance (or is not noticeably moved) can you estimate the force or pressure? (*e*) In general terms, compare the effect of the stroke of a monkey of, say 4 cwt., falling 14 feet, with that of the monkey and fall given above. (51.)

(24.) *52. Trace, in ink, the Ionic volute curve shown, and the words "Ionic volute." (This curve is a series of quadrants of circles: it is important—for full marks—that the line shall be uniform and that no points of junction shall show.) (45.)

1903.

HONOURS—PART II.

NOTE.—No Candidate will be credited with a success in Part II.—Honours who has not obtained a previous success in Honours.

INSTRUCTIONS.

Read the General Instructions on page 701.

You may not answer more than five questions, one of which, and not more, must be selected from each of the first two divisions. You must also attempt the tracing.

The sketches, questions (61) and (62), should be drawn on the drawing paper—not on the squared paper: they may be first sketched in pencil, but they are expected to be neatly finished, as pen sketches, in Indian ink.

The other sketches should be clear and effective. Candidates may (in this stage) draw them either on the squared paper or on the drawing paper. Writing on squared paper and on foolscap should be in ink.

DIVISION I.

(25.) 61. Answer one only of the following (*a*), (*b*), (*c*), or (*d*):—

(*a*) Draw, to fill a space $2\frac{1}{2}''$ deep and $5''$ long, the Greek double guilloche ornament. (80.)

(*b*) Sketch, to fill a band $2\frac{1}{2}''$ deep, the complete honeysuckle and lotus, or papyrus and lotus, Greek ornament. (80.)

(*c*) Draw faintly in pencil 14 parallel straight lines $\frac{3}{16}''$ apart; on these, making use of them, work a Greek fret. (80.)

(*d*) What is a *Choragic* monument? Describe the Choragic Monument of Lysicrates. Sketch the termination of a flute (at its top). (80.)

(26.) 62. Answer one only of the following (*a*), (*b*), or (*c*):—

(*a*) Sketch for each of the "styles":—Norman, Early English, Decorated, and Perpendicular,—at least one characteristic moulding ornament. (80.)

(*b*) Sketch for each of the "styles":—Norman, Early English, Decorated, and Perpendicular,—the top of a buttress. (80.)

(*c*) Sketch a Moorish Capital (Alhambra) with fairly elaborate ornament. (80.)

DIVISION II.

(27) *63. The drawing shows the plan and the front elevation of a cottage which has been built for the accommodation of a clergyman. Write down full instructions which would be sufficient to guide an assistant to write a complete specification for the work, to be executed by contract.

Instruct him as to *detail* drawings. Note for his guidance any small omissions on the drawing. (80.)

(See note, question 65.)

(28.) 64. Make such sketches as will enable an assistant to make complete drawings for a switch and signal cabin at a village railway station. Write full instructions from

which he can write a specification for the work, which is to be done by contract (omit levers and electrical arrangements). (80.)

Division III.

(29.) *65. Take accurate quantities of the masonry and brickwork of question 63. Bring them into bill and estimate the cost in detail. (Candidates, who prefer to do so, may assume the outside walls to be of brickwork 9″ thick, keeping the outer faces as shown: this note also applies to question 63.) (80.)

(30.) 66. Take accurate quantities for the signal and switch cabin, question 64, bring them into bill and estimate the cost in detail. (Omit levers and electrical arrangements.) (80.)

(31.) 67. You have to carry a railway through a hill; the surface of the ground is 40 feet above the "formation" surface of the railway (that is the surface which is prepared to receive the ballast to sustain the sleepers); the total breadth of the formation and drains is 25′: the slopes in open cutting would be secure at 1 to 1; the ground is easy to get and to fill: you have to decide whether;—(*a*) you will have an open cutting with slopes the whole way down to the formation; (*b*) you will have an open cutting with revetment walls; (*c*) you will excavate a tunnel and line it with brickwork: describe in what way you will seek to come to a sound conclusion (the question is one of cost only). Sketch half cross sections of (*a*) open cutting the full depth; (*b*) open cutting with revetment walls 10 feet high; (*c*) the tunnel: stone costs 3*s*. a ton, bricks 35*s*. a thousand, Portland cement 40*s*. a ton, sand $2\frac{1}{2}d$. a bushel. Find the cost of a yard forward on each assumption. (80.)

(32.) 68. Coating iron with zinc in the manner called "galvanizing" protects the iron from rusting at scratches which expose the iron surface, and at small bare areas wider than scratches make; coating iron with tin does not protect the iron in the same way: explain this. (80.)

(33.) 69. Write instructions for a clerk of works (whom you have appointed to supervise the building of a large house); the work is being done by contract; they should regulate his dealing with doubtful materials and workmanship, his reports to you, his attendance on the work, &c., &c. (80.)

(34.) *70. Trace, in ink, the plan of the cottage, also the dimensions and the writing—on the plan. (The lines should be opaque so as to give good prints.) (80.)

SUBJECT III.—BUILDING CONSTRUCTION.

1903.

HONOURS—PART II.—EXAMINATION (DESIGN).

To be worked at South Kensington.

Time allowed, seven hours.

(35.) Design a village elementary school, of one story, for 60 male pupils. The site is a rectangular plot having 100 feet frontage to a public road, and it is 200 feet in depth. In the road there is a public sewer and a water supply main.

Give a skeleton drawing, to a small scale, showing how you place the school; the road runs east and west, and the plot is on the north side of the road. You have to build a boundary wall 6 feet high and to provide for entrance and exit. Give such plans, elevations, and sections, to the scale of $\frac{1}{96}$, as you think sufficient for the letting of the work to be executed by contract. (The soil is compact homogeneous clay.) Candidates should make a list of the items of accommodation which they think necessary; they should provide for this accommodation in the most substantial, efficient and economical ways. The elevations should be appropriate and in good taste. It will be sufficient to draw, in detail, one feature (as a window, etc.) where there are several identically the same. The site may be taken as level. Large scale detail drawings are not expected.

SUBJECT III.—BUILDING CONSTRUCTION.

1904.

STAGE 2, STAGE 3, AND HONOURS.

General Instructions.

Before commencing your work, you must carefully read the following instructions:

You may take Stage 2, or Stage 3, or, if eligible, Honours, but you must confine yourself to one of them.

Drawings must be made on the single sheet of drawing paper supplied, beginning on the side marked with your distinguishing number, which must face you at the right-hand top corner. Sketches may be made by hand on the squared paper attached to the drawing paper. Additional foolscap will, if necessary, be supplied to you by the Superintendents.

The tracing is to be drawn on the piece of tracing paper attached to the drawing paper.

Answers in writing must be as short and clearly stated as possible, and the references to drawings and sketches must be made absolutely clear by letters or numbers.

The value attached to each question is shown in brackets after the question. But a full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

Questions marked (*) have accompanying diagrams.

The examination in this subject lasts for four hours.

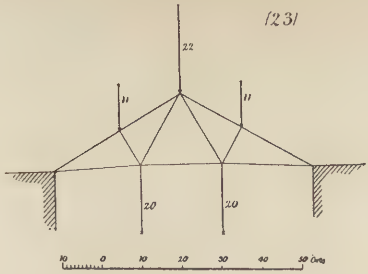
STAGE 2.—1904.

Instructions.

Read the General Instructions, pages 701 and 716.

You may not answer more than six questions.

[23]



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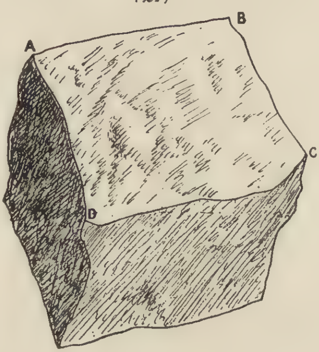

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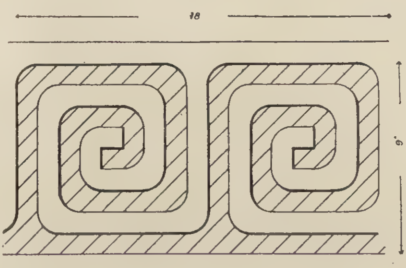


Straight Lines & Curves.

The drawing in answer to Question 23 should be on the drawing paper; it may be in pencil. Written answers on squared paper and on foolscap should be in ink. The sketches on squared paper may be in pencil; candidates may, however, if they think it an advantage, outline the pencil sketch, with the writing pen, in ink.

(36.) 21. It is commonly specified that the stones of masonry are to be laid on their natural beds; there are exceptions to this rule; for what purpose should stones be built with their planes of beddings vertical?

What do you understand by the *natural* beds of building stones? Describe building stones which do not show "bedding." Describe *cleavage* as distinct from bedding. (24.)

(37.) 22. A good straight grained piece of timber dressed to a square cross section $1'' \times 1''$ placed horizontally on supports 12 inches apart breaks under a load of 544 lbs. applied gradually at the point midway between the points of support. You have to make use of a beam of rectangular cross-section of this timber to carry *safely* a uniformly distributed load of 10 tons over a span of 16 feet; the factor of safety is 6; the breadth of the beam is 9 inches. What should be its depth? (*Note.*—The strength of a beam of rectangular cross-section is proportional to its breadth, to the square of its depth, and inversely to its length:

$$S \propto \frac{bd^2}{l}.)$$ (36.)

(38.) *23. Draw the figure and scale on your paper.

Draw a diagram to the scale given which will show the stresses resulting from the applied loads in the members of the roof truss shown as a skeleton: mark each member which is in compression with the sign $+$.

(It is assumed that the longitudinal axes of symmetry of the members all lie in one plane (the plane of the paper) and that they are connected at the joints by smooth pins which are at right angles to this plane.) (36.)

(39.) 24. In connection with wood-working machinery, what is *Slot Morticing?* What advantage has it over chisel morticing? What various operations can be effected by the tool called a "General Joiner"? (In this question slot morticing is not restricted to mortices open at one end which are known as *slot* mortices.) (33.)

(40.) 25. Describe the structural differences as far as you know them between what are called "hard woods" and "soft woods." Classify the following as "hard woods" and "soft woods":—mahogany, willow, yew, pitch pine, cedar of Lebanon, alder, walnut. (24.)

(41.) 26. In a brick wall, $2\frac{1}{2}$ bricks thick, what is the face area of a rod of such work? Sketch on your squared paper (assuming the distance between a pair of the lines to represent 3″) about a square yard of the elevation of one face of this wall, in English bond. The bricks are $9'' \times 4\frac{3}{8}'' \times 2\frac{3}{4}''$, and the joints are $\frac{1}{4}''$. How many facing bricks are in a square yard (supposing there are no bats)? (33.)

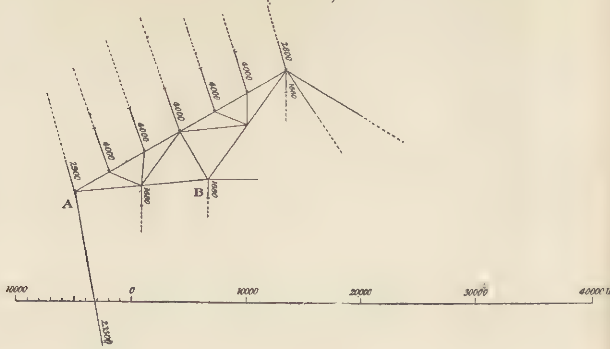
(42.) *27. Answer only one of the following (*a*) or (*b*):—

(*a*.) The figure shows a block of stone which is to be dressed; sketch it, approximately, upon your squared paper (the space between two lines may be taken as 4″ wide). The face *ABCD* is to be dressed to a true plane. Show by sketches how this is done. Give any written explanations you think necessary. (29.)

(*b*.) Sketch upon your squared paper (assuming the distance between a pair of lines to represent 2″) a block of rock-faced ashlar (margined) just being lowered to its bed. The face of the stone is 3′ long and 1′ 4″ high. Show how the stone is held by the suspending tackle. (29.)

(43.) 28. Sketch upon your squared paper a boot boiler and a hot-water cylinder (the distance between two lines

(45 & 50)



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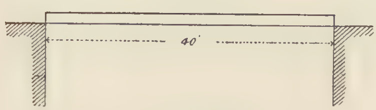

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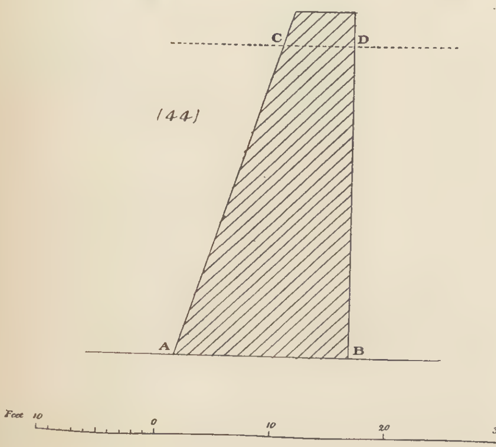

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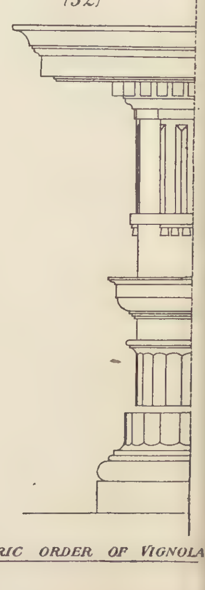


DORIC ORDER OF VIGNOLA

represents 6″). Assume a cold-water supply tank. Show in diagram the pipes between the cold-water tank and the boiler and the cylinder. Show a pipe with bib-cock from which a supply of hot water may be obtained. (*Note.*—There should be 3 pipes to the boiler, viz., the cold-water and the two circulating pipes. It is a common error to bring the cold water into the cylinder every time there is a draw-off.) Why is it necessary to have a cold-water tank connected with the water main by a ball-cock? (30.)

(44.) 29. Describe the complete operation of producing a plane surface in plasterer's work, lathed on battens; the work to be of the best class finished to be painted. Describe the preparation of materials for the several coatings. (24.)

(45.) 30. Describe the complete operation of painting a new outside door, commencing with the priming: to be grained imitation oak and finished in what you think is the best manner to withstand the effects of the sun and weather. (24.)

(46.) 31. Show by neat sketches on your squared paper (distance between a pair of lines to represent 4″) a cast-iron sky-light glass area 3′ × 1′ 8″. Show how it is fitted to the opening in the rafters. Show how the slates are fitted round it. Show such lead flashings, &c., as you think will make a perfectly good water-tight work. The slates are 24″ long, lap 4″. (33.)

(47.) *32. Trace neatly in ink the drawing shown, also the writing and the figures. (The Indian ink should be sufficiently thick to give opaque lines suitable for photographic printing: the lines should be well defined, having firm unbroken edges; they should neither stop short nor go beyond the proper points.) (29.)

STAGE 3.—1904.

Instructions.

Read the General Instructions, on pages 701 and 716.

You may not answer more than six questions, of which a least one must be selected from each of the first two divisions: the tracing Question 52, must be attempted by all candidates.

Sketches and answers may be on the squared paper which is attached to the drawing paper. Additional foolscap may be obtained from the Superintendents of the examination.

The tracing should be drawn on the tracing paper attached to the drawing paper.

The drawings, in answer to Questions 44 and 45, should be on the drawing paper; they may be in pencil.

Writing on foolscap and on squared paper should be in ink.

Division I.

(48.) 41. Describe fully the complete operation of the manufacture of Baltic flooring boards, of uniform thickness, tongued and grooved, having true edges and surface, ready for laying, as they may now be obtained from timber merchants. Begin your description at the stage when timber is to be sawn into boards. (50.)

(49.) 42. What are the principal defects to be looked for in cast-iron and steel? Write a full description of the conditions which should be complied with by (*a*) cast-iron columns and (*b*) riveted steel girders for use in an important building. Describe the tests which you would apply to see that these conditions are fulfilled. (50.)

(50.) 43. What is selenitic cement? Describe its manufacture, state for what purposes it is advantageous and what precautions must be taken in using it. (50.)

Division II.

(51.) *44. A long straight wall, built of, say, granite in cement mortar having the vertical cross-section shown, is proposed

to be built to retain water; it may be supposed to act as one block resting on a thin mortar bed at AB, which is supposed to be water-tight; the friction on AB is sufficient to prevent sliding on the bed so that the tendency of the wall to fail is by overturning; the weight of the wall is 170 lbs. per cubic foot; when the water stands at the level CD on the AC side of the wall, what is the pressure in lbs. per square foot on the bed at A and what is the pressure in lbs. per square foot on the bed at B?

Again, suppose the wall to be built so that the face BD is next the water, what is now the pressure in lbs. per square foot at A and at B? Why is it advisable that the line of direction of action of the resultant pressure should meet the bed-joint at a point more than one-third of the length of AB from A when the water is on the side BD or from B when the water is on the side AC? (60.)

(52.) *45. Given a portion of a roof-truss in skeleton as shown stressed by the forces shown. Draw a stress diagram to show the stresses in the several members of the truss.

Note.—The assumption is made that these members have their axes of symmetry in one plane and that the lines of action of the applied forces are all in the same plane and that all the members which meet at any point are each (if not held elsewhere) free to move round a pin at the point, and that these pins are at right angles to the plane of the forces, represented by the plane of the paper. (60.)

(53.) *46. A wooden beam of uniform rectangular cross-section ($d = 18'' \times b = 14''$) rests horizontally on supports 40 feet apart: it weighs 80 lbs. per foot of length: what is the bending moment at cross-section 15 feet from one end? Explain in what way the material of the beam resists the bending moment. What is the *moment of inertia* of a cross-section? What connection has such a quantity with the resistance to the bending moment? (50.)

Division III.

(54.) 47. In the basement of an existing bank a strong room for the storage of books and papers is to be constructed. The floor of the basement consists of wooden joists and floor boards, and the ceiling is plastered on wooden joists. Draw a plan of the room (14′ × 12′ inside measurements) and cross-section (height of basement 11 feet floor to ceiling), and describe fully how you would build the room to ensure its being both fire proof and damp proof. (50.)

(55.) 48. The ground floor of a building without a basement shows signs of weakness and suspicions of dry rot are entertained. Describe clearly and fully the measures you would adopt to ascertain if this is the case, and how you would endeavour to eradicate it and prevent its recurrence. (50.)

(56.) 49. What is meant by the "Plenum" system of ventilation? Describe its action, and give your reasons for thinking such a system desirable or the reverse for (*a*) a picture gallery, (*b*) a board school, or (*c*) a hospital. (50.)

(57.) *50. The roof truss shown is supposed to be a good form for a wide span: what can you say in its favour for such a purpose (the hanging loads represent the weight of the ceiling).

Sketch upon your squared paper (assume that the distance between two lines represents 3 inches) the joint and bearing at A and the joint at B. Sketch cross-sections of the members which meet at the joint, and give their weights per foot of length (adopt a factor of safety of 6). (50.)

(58.) 51. Describe carefully the chemical composition of any two building stones, and state for what purposes you would consider them suitable. (50.)

(59.) *52. Trace in ink the column and entablature given.

N.B.—Marks will not be given for this question unless the tracing is very carefully and neatly made. (30.)

HONOURS.—1904.

Instructions.

Read the General Instructions, on pages 701 and 716.

No Candidate will be credited with a success in this examination who has not obtained a success in an examination corresponding to Stage 3 of the same subject (*i.e.*, in Honours, or Honours, Part I., under previous regulations).

You may not answer more than five questions. You are required to attempt one question, and not more, from each of the Divisions I. and II.; the remaining questions must be selected from Division III.

The drawings, 61 (*a*) and (*c*), and 62 (*b*) and (*c*), should be finished as neat pen and Indian ink drawings. The drawings, Questions 67 and 68, may be left in pencil. All of these drawings should be on the drawing paper supplied to the candidates.

Writing on squared paper and on foolscap should be in ink.

Division I.

(60.) 61. Only one of the following questions (*a*), (*b*), (*c*) is to be attempted :—

(*a*.) Draw carefully a typical Greek Ionic capital and describe concisely the modifications which the Romans made in the Ionic Order. (80.)

(*b*.) Describe and illustrate by rough sketches one only of the following buildings:—1. The Erechtheum. 2. The Temple of Nikè Apteros. 3. The Maison Carrée at Nîmes. 4. The Pantheon at Rome. (80.)

(*c*.) Draw in elevation (about 5 inches high on the paper) the angle of a Roman Ionic entablature with the capital and a small portion of the column supporting it. (80.)

(61.) 62. Only one of the following questions (*a*), (*b*), (*c*) is to be attempted:—

(*a*.) Describe and illustrate by sketches the development of window tracery in English Ecclesiastical buildings. (80.)

(*b*.) Draw sections half full size of the moulded cap and base of a 5 inch diameter circular shaft of the thirteenth, fourteenth and fifteenth centuries respectively. (80.)

(*c*.) Draw full size sections of an external hood mould in the Norman, Early English, Decorated, and Perpendicular styles. (80.)

DIVISION II.

(62.) 63. In a hospital there are latrine blocks on the ground, first, and second floors, one over the other; there are three waterclosets in each block: write a full specification of the plumber's work, and describe how the pipes are to be tested. (80.)

(63.) 64. Answer only one of the following (*a*) or (*b*):—

(*a*.) Write a form of advertisement for tenders for building a house at
for .

Write a form of tender for the work.

Write down the margina précis of the clauses of a short "Schedule of Conditions" for the building contract for this work (say 19 clauses). (80.)

(*b*.) Write a short concise specification for building a retaining wall in rubble masonry, Portland cement mortar and Portland cement concrete; describing the character of the materials, the proportions and tests. (80.)

DIVISION III.

(64.) 65. A detached building 32′ × 16′, inside of walls, is covered by a lead flat surrounded by parapet walls rising

2′ 6″ above the flat: draw, $\frac{1}{8}''$ to a foot, a plan of the flat showing rolls and drips, and a section, $\frac{1}{2}''$ to a foot, through the walls showing the cover flashing. Take out the quantities for the rough boarding and the lead. (80.)

(65.) 66. What is meant by combined drainage? Under what conditions would you allow such a system of drainage to be adopted in a row of small houses? (80.)

(66.) 67. Draw to a scale of $\frac{1}{8}''$ to a foot plan and cross-section of a classroom for 24 girls in a secondary school, show the desks, windows and door, describe how you would ventilate the room. (80.)

(67.) 68. The dining room of a large country house is to have a panelled oak dado, 7 feet high, all round the walls, draw $\frac{1}{2}''$ to a foot, an elevation of about 8 feet of the panelling, draw to the scale of $\frac{1}{8}$ of full size a sectional plan through a stile and a panel, draw to the scale of $\frac{1}{8}$ of full size cross-sections of top rail and capping and of bottom rail and plinth. (80.)

(68.) 69. A water tank is formed by a circular wall resting on a level bed. Its cross-section is such that the top of the wall is level and 3′ wide, and the wall is 20′ wide at the bottom. It is 30′ high; the batter of the inside is 2″ to 1′; its outer slope is uniform; the radius of the tank at the floor (the bottom of the wall) is 25′. Calculate *accurately* the quantity of masonry in the wall in cubic yards. (80.)

(69.) 70. For the construction of a swimming bath describe fully and clearly in the form of a letter of instructions to the clerk of works the precautions which you would adopt to ensure the sides and bottom of the bath being thoroughly water-tight. The materials to be used to be fully particularised. (80.)

BUILDING CONSTRUCTION.—HONOURS.

(Design.)

EXAMINATION AT SOUTH KENSINGTON, 1904.

Time allowed, seven hours.

(70.) Subject.—A detached house for a country doctor. The site is level, on the north side of a main road and with a frontage to it of 85 feet, depth unlimited. The house to be set back from the road 25 feet. Accommodation required:—On the ground floor: entrance hall; dining and drawing rooms, each with an area of about 220 feet; kitchen, scullery, and ordinary domestic offices; surgery, communicating with house, and also with a waiting room, the latter to have an area of about 170 feet and to have a separate approach from the outside; a W.C. to be arranged easy of access from the surgery. On the upper floor, 5 bedrooms, bathroom, and W.C.

The drawings required are:—Plan of each floor, one section indicating the roof construction, front elevation (these to be drawn to a scale of 8 feet to an inch); a block plan showing the position of the house on the site, to a scale of 32 feet to an inch.

BOARD OF EDUCATION, SOUTH KENSINGTON.

ART EXAMINATION PAPER.

ARCHITECTURAL DESIGN, 1904.

30TH MAY TO 1ST JUNE, 1904.

4 to 10 p.m. each day.

GENERAL INSTRUCTIONS.

Before commencing your work, you must carefully read the following instructions.

You must first answer one and not more than two of the questions 1—3 and give your answers to the officer in charge before the interval at 7 p.m. on May 30th.

You must then draw out a general scheme for your design which shall show your proposed treatment of the subject.

You will be required to show these rough drawings to the officer in charge during the first evening's examination, and you will not be permitted afterwards to change your scheme.

No part of the drawings need be inked in.

Your name may be written only upon the numbered slip attached to your drawing paper.

QUESTIONS.

(71.) 1. What are the materials used in covering roofs? Name them in the order of excellence according to your judgment. And describe in detail those with which you are most familiar.

What is meant by gauge, lap, verge, tilting, fillet, soaker, flashing? (20.)

(72.) 2. Describe system of drainage for a small house, giving size of pipes, position of traps, ventilators, cesspool, &c. (20.)

(73.) 3. What is meant by damp course?

What materials may be used for this purpose? Where would you place it when using wood blocks on ground floor?

What is the meaning of a vertical damp course? (10.)

SUBJECT.

Design a Village Club.

The building to contain the following accommodation:—

(74.) 1. Large hall, say 30 feet by 60 feet, for entertainments, with stage at one end and a gallery at the other. An external entrance as well as direct communication with the rest of the club buildings.

(75.) 2. Reading room, say 20 feet by 30 feet, and entrance hall say 20 feet by 15 feet, where refreshments can be obtained.

(76.) 3. Caretaker's apartments so arranged that direct supervision can be exercised over reading room and entrance hall. Caretaker to have in addition living room, kitchen and usual offices, with staircase leading to bedrooms (which need not be shown) and back entrance.

Suitable lavatory and sanitary conveniences must be provided. The site is rectangular, 120 by 100 feet (with light obtainable on all sides), at the intersection of two streets.

Any British style of architecture may be adopted, but half timber work should if possible be avoided. The building should be simple in design so as to harmonise with its surroundings.

No sketch plan is provided, but it is suggested that an L-shaped building would best meet the requirements; the

hall occupying the space represented by the base of the letter.

The drawings required are :—

1. Ground plan; 2, Elevation; 3, Section, all drawn to a scale of one-eighth of an inch to one foot.

A further drawing must be attempted, either—

1. A drawing showing treatment of stage.
2. A drawing showing treatment of gallery.
3. A perspective.

The two first to be drawn to a scale of a quarter of an inch to one foot.

SUBJECT III.—BUILDING CONSTRUCTION.

1905.

ADVANCED OR STAGE 2.

INSTRUCTIONS.

Read the General Instructions on pages 701 and 716.

You must not attempt more than *six* questions in all, and of these No. 21 must be one; that is to say, you are allowed to take not more than five questions in addition to No. 21.

The drawings in answer to Questions 23, 24, 25, 27, 28 and 32 should be on the numbered side of the drawing paper; they may be in pencil. Written answers on squared paper and on foolscap should be in ink. The sketches on squared paper may be in pencil; candidates may, however, if they think it an advantage, outline the pencil sketch, with the writing pen, in ink.

(77.) *21. Make a neat tracing in ink of the drawing, Figure 21, with the writing and figures. The lines should be firm and unbroken and should finish exactly at the proper points. (30.)

(78.) 22. A pier hole, 5 feet square and 10 feet deep, has to be sunk in loose earth which has a tendency to cave in. Describe fully the planking and strutting which would be required for this excavation; illustrate your answer by sketches, figuring the scantlings. (25.)

(79.) 23. A hollow brick wall consists of a 9-inch and a $4\frac{1}{2}$-inch wall separated by a 2-inch cavity: the bottom of the footings is 2 feet below ground level and the floor level is 2 feet above ground. Draw to a scale of $\frac{1}{8}$ ($1\frac{1}{2}$-inch to a foot) the complete section through the wall—including end of floor joist—to a height of about 5 feet 6 inches from under side of concrete foundation. (25.)

(80.) *24. The diagram shows plan of part of a bay window in an 18-inch brick wall. Draw to a scale of $\frac{1}{8}$ ($1\frac{1}{2}$ inch to a foot) the bonding of two consecutive courses in English bond at the angle below the window opening, and also to the same scale the bonding of two courses for the angle pier between the openings. (35.)

(81.) 25. In a three-storied house the fire openings on the ground, first, and second floors are over one another and are respectively 4 feet 3 inches, 3 feet, and 2 feet 6 inches wide : the top floor is 9 feet high from floor to ceiling and the other heights are 13 feet and 11 feet 6 inches from floor to floor starting at ground floor level. Draw an elevation of the chimney breast from ground floor level to second floor ceiling and show the course of the flues—which are to be 9 inches square—by dotted lines: scale $\frac{1}{48}$ ($\frac{1}{4}$ inch to a foot). (30.)

(82.) *26. Answer either (*a*) or (*b*), but *not both :*

(*a*.) Describe fully the quarrying and preparation of Kentish rag stone for face work with the tools employed. (25.)

(*b*.) The diagram shows a two-light window opening in a stone wall. Sketch it on your squared paper and add the jointing, giving your reasons for the particular positions of the important joints. (25.)

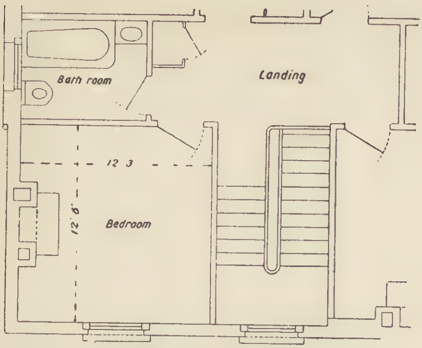
(83.) *27. The diagram is the sketch plan of a room on an upper floor : copy it on your paper and show by dotted lines the joists, trimmers, &c., and state what should be their scantlings. (25.)

(84.) *28. The diagram shows the space for an open newel stair case to rise 14 feet from floor to floor starting at the point *x*. Draw a plan of the staircase showing the newels, and a sectional elevation on the line *AA;* no winders are to be used. (30.)

(85.) 29. Give an outline sketch showing the general arrangement of a band saw. What is the approximate velocity of such a saw in feet per minute? State what class of work it is used for, and name examples. Describe how the saw resists the pressure of the wood and how it is made into a continuous ribbon. (25.)

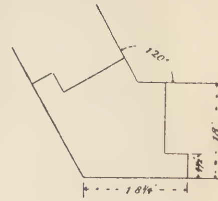
(86.) 30. A rectangular timber beam 16 feet between supports will safely carry a distributed load of 3 tons : what would be the safe load concentrated on the same beam at a distance of 4 feet from one end? (25.)

SUBJECT III. *Stage 2, 1905.*



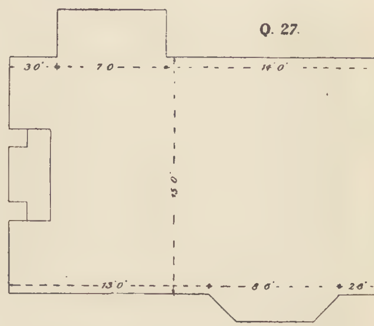
FIRST FLOOR PLAN.

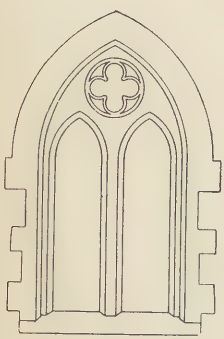
Q 21.



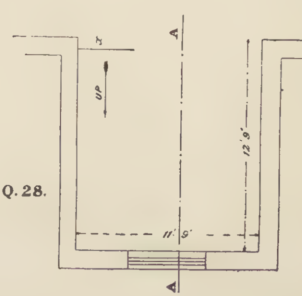
Q 24

Q. 27.





Q 26.

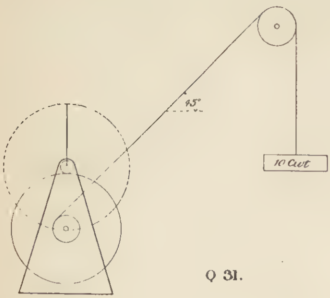


Q. 28.

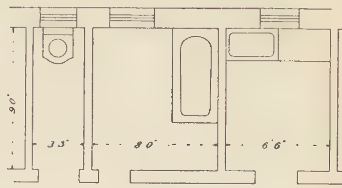
(87.) *31. The diagram shows a single purchase crab used for lifting weights of 10 cwts. The chain leaves the drum at an angle of 45°, and passing over a pulley supported at a height lifts the load vertically. Sketch the figure on your own paper, and mark on it the approximate radius of handle, number of teeth in pinion and wheel, diameter of drum and number of men required, assuming 15 lbs. effective per man. Show by the parallelogram of forces the stress on upper pulley. (35.)

(88.) *32. The plan shows the identical arrangement on 3 floors one over the other, of a w.c., bath and housemaid's sink (not a slop sink). Draw an external elevation of the wall showing all the pipes which you would consider necessary. Assume the height of floors 10 feet each. (40.)

SUBJECT III. *Stage 2, 1905. (Continued)*

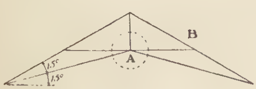


Q 31.

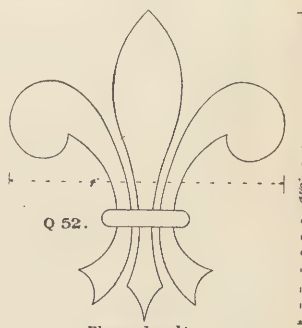


Q. 32.

SUBJECT III. *Stage 3. 1905.*

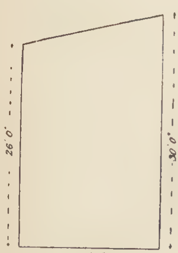


Q 46.

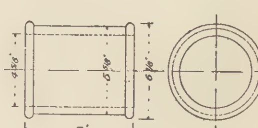


Q 52.

Fleur-de-lis



Q. 44.



Q 51.

STAGE 3.—1905.

INSTRUCTIONS.

Read the General Instructions on pages 701 and 716.

You may not answer more than six questions, of which one only must be selected from each of the first two divisions: the tracing Question 52 must be attempted by all candidates.

Sketches and answers may be on the squared paper which is attached to the drawing paper. Additional foolscap may be obtained from the Superintendents of the examination.

The tracing should be drawn on the tracing paper attached to the drawing paper.

The drawings in answer to Questions 44, 45, 46, and 50 should be on the numbered side of the drawing paper; they may be in pencil.

Writing on foolscap and on squared paper should be in ink.

DIVISION I.

(89.) 41. What is the chemical composition of the ordinary kinds of marble, and to what are the various tints attributable? Do you consider marble a good material to use for (*a*) outside works in towns, and (*b*) internal staircases? Give your reasons fully. (50.)

(90.) 42. Describe how you would select "good middling" Memel in the balk under the head of marks, characteristics, and defects. For what purposes would such timber be used, and what preparations for each purpose should it undergo? (50.)

(91.) 43. What are the relative advantages and drawbacks of glazed stoneware and cast-iron pipes for domestic drainage? Describe fully the tests which you would apply to the sanitary arrangements of a town house in a terrace which are suspected of being at fault. (50.)

Division II.

(92.) *44. The building, of which diagram 44 is a sketch plan, is to be covered with a roof of 45° pitch, hipped at each end: draw to a scale of $\frac{1}{96}$ ($\frac{1}{8}$ inch to a foot) a plan of the roof and determine accurately the length of the hip rafters. (50.)

(93.) 45. A beam with a clear span of 16 feet carries a 9-inch brick wall 12 feet high over half its length from one support. Draw a bending moment diagram, and a shear stress diagram, and find the reaction at each support: scales $\frac{1}{4}$ inch to a foot, 100 foot-cwts. to one inch, and twenty cwts. to one inch. Assuming that a rolled-steel joist is to be adopted, what strength-modulus of section would be required so that the maximum stress on the outer fibres should not exceed 8 tons per square inch? (60.)

(94.) *46. Fig. 46 shows a skeleton diagram of a steel roof-truss 25 feet span. Assuming the trusses to be 7 feet apart, the load to be 28 lbs. per foot super over the sloping surface, and a wind pressure of 28 lbs. per foot super normal to the slope on side *B*, draw the truss to a scale of $\frac{1}{48}$ ($\frac{1}{4}$ inch to a foot) and a complete stress diagram to a scale of 10 cwts. to an inch. Sketch half full size an elevation of the joint at *A* and an approximate section of the members. (60.)

Division III.

(95.) 47. A building is to be erected with a basement 12 feet below ground level: at a depth of 4 feet the site is very damp, and the permanent water level of the site is at 10 feet depth. Describe fully the precautions which you would take to ensure a perfectly dry basement. (50.)

(96.) 48. Sketch on your squared paper, to a scale of $\frac{1}{48}$ ($\frac{1}{4}$ inch to a foot), a hammer beam roof truss for a span of 25 feet. Name the various members, and figure their scantlings. What are the advantages of this kind of roof, and the precautions necessary in using it? How are the trusses placed in position? (50.)

(97.) 49. A stone column with carved capital in the nave of a church shows signs of settlement, and requires to be underpinned: describe carefully and illustrate by sketches the method of shoring and underpinning it. (50.)

(98.) 50. An oriel window, semi-circular in plan and 5 feet outside diameter, is required in a stone building: give detail drawings illustrating the construction of the lower portion up to floor level, assuming the main wall to be 18″ thick, scale $\frac{1}{16}$ ($\frac{3}{4}$ inch to a foot). (50.)

(99.) *51. The diagram shows a cast-iron thimble for connecting the spigot-ends of two 3-inch socket pipes. Describe with sketches the construction of a wood pattern for this, and the method of moulding in the foundry and running the casting. (50.)

(100.) *52. Trace neatly in ink the drawing fig. 52 with writing and figures: the lines should be firm and unbroken, and should finish exactly at the proper points. (30.)

SUBJECT III.—BUILDING CONSTRUCTION.

HONOURS.—1905.

INSTRUCTIONS.

Read the General Instructions on pages 701 and 716.

No Candidate will be credited with a success in this examination who has not attained a previous success in Stage 3, or in Honours, of the same subject, and who does not qualify in the Board's examination in Architecture.

You may not answer more than five questions.

The drawings 61, 65, and 67 should be on the drawing paper supplied to the candidates, and may be in pencil.

Writing on squared paper and on foolscap should be in ink.

(101.) 61. A detached warehouse containing 5 floors, the walls of which are 60 feet high from top of footings to parapet, is to be built on loose soil near a tidal river. It is decided that a concrete and steel raft is necessary as a foundation. Describe fully the construction of such a raft, and state what are the risks to be guarded against in building on such a site, and the principal precautions which have to be taken. Draw, to a scale of $\frac{1}{16}$ ($\frac{3}{4}$ inch to a foot), a section through the base of one of the outer walls, including footings and concrete. (80.)

(102.) 62. Describe fully the constituents of and the process of manufacture of any artificial stone used in building, and state for what purpose you would consider it suitable, and the drawbacks attending its use. (70.)

(103.) 63. The upper half of the front wall of a four-story building, 43 feet in height above the pavement level, shows signs of bulging out, and is to be shored up. The street upon which the building fronts has a total width of 24 feet

from house to house, of which the foot pavement on each side is 4 feet wide, and the roadway 16 feet. Describe and illustrate by sketches to a scale of $\frac{1}{48}$ ($\frac{1}{4}$ inch to a foot) how you would arrange the shoring, so as not to interrupt the traffic in the roadway. The houses opposite are small and in bad repair. (90.)

(104.) 64. What are the essential principles of ferro-concrete construction? Describe fully any one form with which you are acquainted, and state what are the main points to which attention must be paid when used in floors and supports. (80.)

(105.) 65. Draw a plan and cross section to a scale of $\frac{1}{48}$ ($\frac{1}{4}$ inch to a foot) of a 6-stall stable: show the doors, windows, and stall divisions, and explain clearly how you would drain and ventilate it, and the kind of paving which you would adopt. (70.)

(106.) 66. A room is to be built for use as a drill hall, 108 feet long and 40 feet broad; there is a basement under, in which may be placed a central row of columns 12 feet apart. State what external load per foot super should be allowed for, and write a careful description of the way in which you would construct the floor, with sketches and figured scantlings. (70.)

(107.) 67. Make a plan section and elevation to a scale of $\frac{1}{24}$ ($\frac{1}{2}$ an inch to a foot) of a dormer window in a slated roof of 45° pitch: the width over all is to be 6 feet 6 inches, and it is to be divided into 2 lights with central mullion, and to have solid casements opening outwards. The dormer is to be covered with a lead flat. Sketch details of the framing, and describe fully the covering of the sides and the precautions to be taken for keeping the water out. (70.)

(108.) 68. A music-practising room is to be constructed on the upper floor of a building. Describe fully the precautions you would take to prevent sound from passing through the floor and the internal partitions. Illustrate your answer by sketches. (80.)

(109.) 69. Write a detailed specification for the construction of a large underground tank for storing, say, 10,000 gallons of rain water for domestic purposes. The soil is loose sand, and the walls are to be of brick or stone and roofed in the same material. Special attention must be given to rendering the tank watertight. (70.)

(110.) 70. What constitutes a continuous beam? In a girder, supported in the centre as well as at the ends, what are the conditions to be fulfilled by the supports for the actual stresses to agree with the calculated stresses? If a rolled joist is built into a brick wall at each end, under what conditions will this become a continuous beam, and by how much will the strength be increased over that of the me joist simply supported at the ends? (70.)

BUILDING CONSTRUCTION.—HONOURS.

(SUBJECT FOR DESIGN.)

EXAMINATION AT SOUTH KENSINGTON, 1905.

Time allowed, seven hours.

(111.) A pair of semi-detached cottages for superior artizans, on a site having 50 feet frontage to a main road and of unlimited depth. The cottages are to be set back from the road 12 feet, and ample space is to be allowed for getting from the front to the back gardens on each side. Accommodation as follows :—On ground floor : living room, kitchen, scullery and pantry, with wash-house, w.c. and coal store arranged as outbuildings ; on first floor, three bedrooms each to be separately approached, and bathroom.

Drawings required : Plans of ground and first floor, one section which must be taken through the staircase, front and one side elevation all to a scale of $\frac{1}{8}$ of an inch to a foot, and detail elevation of the front of one cottage to $\frac{1}{2}$-inch scale. On the ground plan is to be shown the front fence and the paths leading from the entrance gates to the front doors, and the division fence between the front gardens, also the lines of drainage, the sewer being in the main road. Extravagance whether in size or treatment is to be avoided, but a picturesque elevation is desired. An estimate of cost of the cottages is to be given.

SUBJECT III.—BUILDING CONSTRUCTION.

1906.

ADVANCED OR STAGE II.

Instructions.

Read the general instructions on pages 701 and 716.

You must not attempt more than six questions in all, and of these No. 21 must be one; that is to say, you are allowed to take not more that five questions in addition to No. 21.

(112.) *21. Make a neat tracing in ink of the drawing figure 21 with the writing and figures. The lines should be firm and solid and should finish accurately at the proper points. (30.)

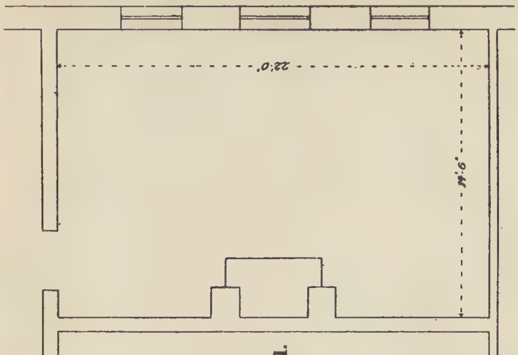
(113.) 22. Describe fully the preparation of the trench, the mixing and laying of the concrete, and the laying and jointing of the pipes in a straight run of 4-inch glazed stoneware house drain laid at an average depth of 3 feet. Draw, half-full size, a longitudinal section through one of the joints. (25.)

(114.) 23. Draw to a scale of $\frac{1}{12}$ (1″ to a foot) the elevation of 4 feet run of a half-brick honey-combed sleeper wall 8 courses high including footing, and the ends of 4 joists suitable for a span of 6 feet; also draw a cross-section of it showing the sleeper and joist. Show the joints of the brickwork and state under what circumstances a damp proof course would be required. (25.)

(115.) 24. Sketch on your squared paper a hand mortising machine for working timber, and describe how it is used. (25.)

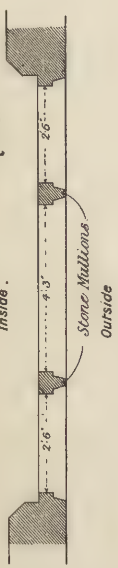
(116.) *25. The diagram, figure 25, shows a three-light opening in a ground floor room; the centre is to have a pair of French casements opening inwards and the side lights double hung sashes. Draw to a scale of $\frac{1}{12}$ (1″ to a foot) a plan through the central and one side opening showing

Stage 2, 1906.

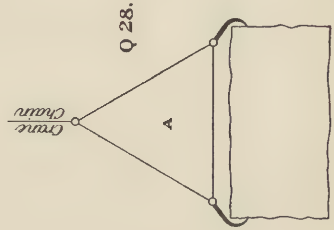


Q 31.

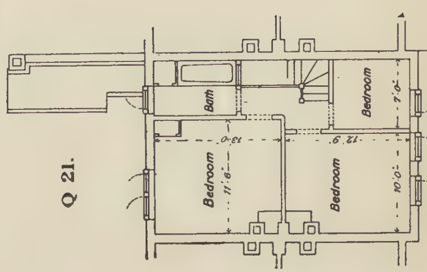
Q 25.



Q 28.



Q 21.



FIRST FLOOR PLAN.

frames, casements, &c., and a vertical section to the same scale through the bottom rail of the French casement. (30.)

26. Explain fully what is meant by the terms "render, float and set" on brickwork. Describe the composition of the stuff used for each operation and the mode of executing it. (25.)

(117.) 27. A cistern is required to hold 1,000 gallons; what should be its length, and of what material should it be constructed if used for storing drinking water? What would be the weight of the water in the cistern when full? (25.)

(118.) *28. The diagram shows a block of stone being lifted by a sling chain and dogs; with a pull of 5 cwt. in the crane chain show graphically what the stress will be in each part of the sling chain surrounding the letter *A*, assuming free play at the eye of the dogs. (30.)

(119.) 29. An internal brick wall 12 feet long has to be removed and replaced by a fir beam which has to carry a distributed load of 4 tons. Calculate the scantling of the beam. If the same load, instead of being distributed, were concentrated at a point 4 ft. from one end, would you consider the beam strong enough? Give your reasons fully. (40.)

(120.) 30. Draw to a scale of $\frac{1}{8}$ ($1\frac{1}{2}''$ to a foot) a section through two consecutive spandril steps with moulded nosings of a hanging stone staircase, and describe clearly how such a staircase is constructed. (35.)

(121.) *31. The diagram is an outline plan of a first floor room which is to have a single-joisted floor; state the number, lengths and scantlings of the timbers which you would require for the plates and joists—including trimmers—for this floor. (30.)

(122.) 32. Explain clearly the various ways in which the water seal of traps of sinks and w.c.'s is lowered and rendered ineffective, and state what precautions you would take to prevent this; illustrate your answer by sketches. (35.)

STAGE III.

Instructions.

Read the general instructions on pages 701 and 716.

You may not answer more than six questions, of which one only must be selected from each of the first two divisions: the tracing Question 52 must be attempted by all candidates.

Division I.

(123.) 41. Describe fully the tests which you would apply on the job to ascertain the quality of a sample of Portland cement submitted to you. (50.)

(124.) 42. Compare the relative advantages of (*a*) marble, (*b*) concrete and iron, and (*c*) solid teak for a staircase from the point of view of resistance to fire. Give your reasons fully. (50.)

(125.) 43. Describe the methods in practical use for preserving timber from the effects of moisture. Classify oak, elm, and fir as to their suitability for use in (*a*) moist ground, (*b*) ground alternately moist and dry, and (c) dry soil. (50.)

Division II.

(126.) *44. The diagram represents, in outline only, a steel Truss for a north light roof. Draw to a scale of $\frac{1}{48}$ (4 ft. to an inch) a suitable truss, and construct the stress diagram for a vertical load of $\frac{1}{2}$ cwt. per foot super to a scale of 20 cwt. to an inch. Draw one quarter full size the detail of joint at foot of north side. The trusses are supposed to be 8 feet apart. (60.)

(127.) 45. A beam 20 feet clear span is subject to a distributed load of 10 tons combined with a central load of 5 tons: draw the bending moment diagram and the shear stress diagram: scales, 4 feet to one inch, 20 ton-feet to an inch, and 10 tons to an inch. What is the value of the bending moment in the centre and the reaction at each end? (60.)

(128.) 46. A compound girder, composed of two rolled steel joists placed side by side with one 12″ × ½″ top plate riveted on, carries in the centre of its span, which is 16 feet clear, a steel stanchion, the weight of which, with its superincumbent load, is 35 tons: calculate the scantling of the joists, and sketch the base of the stanchion and its connection with the girder. (60.)

Division III.

(129.) 47. How does a mason's scaffold differ from a bricklayer's scaffold? Sketch the end view of a mason's scaffold, about 30 feet high, to a scale of $\frac{1}{48}$ (4 feet to an inch): name the parts and mark the scantlings. What is the particular advantage of bracing in scaffolding? (50.)

(130.) 48. Describe clearly, illustrating your answers by sketches, the "cylinder" and "tank" systems of hot water circulation, and state the relative advantages and drawbacks of each system. (50.)

(131.) 49. An 18″ brick wall, with the usual footings and concrete, is to be underpinned to a depth of six feet. Describe fully how this should be done, and draw an elevation and section of the first portion of the completed work to a scale of $\frac{1}{48}$ (4 ft. to an inch) showing the old footings by dotted lines. (50.)

(132.) 50. Draw to a scale of $\frac{1}{48}$ (4 ft. to an inch) a "Belfast" roof truss for 40 ft. span with a rise of 6 ft., with detail of joints one-eighth full size = 1½″ to a foot. (50.)

(133.) 51. A billiard room is to be covered with a lead flat having a lantern light 12 ft. × 6 ft. clear internal dimensions. Draw to a scale of $\frac{1}{12}$ (1″ to a foot) a cross section through the lantern showing 12″ of the lead flat on each side with the trimmers and joists. Describe the precautions which you would take to prevent condensed water falling on the table. (50.)

(134.) *52. Trace neatly in ink the drawing Fig. 52. The lines should be firm and unbroken and should finish exactly at the proper points. (40.)

SUBJECT III.—BUILDING CONSTRUCTION.

1906.

HONOURS.

INSTRUCTIONS.

Read the general instructions on pages 701 and 716.

No candidate will be credited with a success in this examination who has not obtained a previous success in Stage 3 or in Honours, of the same subject, and who does not qualify in the Board's examination in Architecture.

Those candidates who do well in the following paper will be admitted to a practical examination held at South Kensington or some other centre. Candidates admissible to that examination will be so informed in due course. No candidate will be classed in Honours who is not successful in the practical examination.

(135.) 61. What are the main points to be attended to in arranging an efficient system of lightning conductors for a large building? Describe clearly the measures which you would adopt for rendering secure from damage by lightning (*a*) a church; (*b*) a factory chimney; and (*c*) a small powder magazine. (80.)

(136.) 62. A retaining wall with vertical back and battering face is 12 feet high above lower ground level, 1 foot thick at top, and 3 feet thick at bottom; it supports safely a bank of earth level with the top having a natural slope of 45 degrees. Draw the wall to a scale of $\frac{1}{24}$ ($\frac{1}{2}''$ to a foot) and show the line of thrust when the wall weighs 1 cwt. per cubic foot, and the earth 90 lbs. per cubic foot, and calculate the stress on outer edge of base assuming that the wall has no tensile strength. What thickness must a rectangular wall of the same material be to do the same work with the same maximum stress? (80.)

(137.) *63. The diagram shows the plan of a roof covered with slates with lead hips and valleys and ornamental tile

ridging. Write a specification for (1) the joiner's work for one of the dormers; (2) the slating; and (3) the plumber's work. (70.)

(138.) 64. Draw to a scale of $\frac{1}{96}$ (8 ft. to an inch) plan of a class room for 40 infants in an elementary school, showing the entrance door, the windows and the seats; also a cross section passing through one of the windows; also draw to a scale of $\frac{1}{24}$ ($\frac{1}{2}''$ to a foot) cross section through the seats. No fireplace need be shown. (80.)

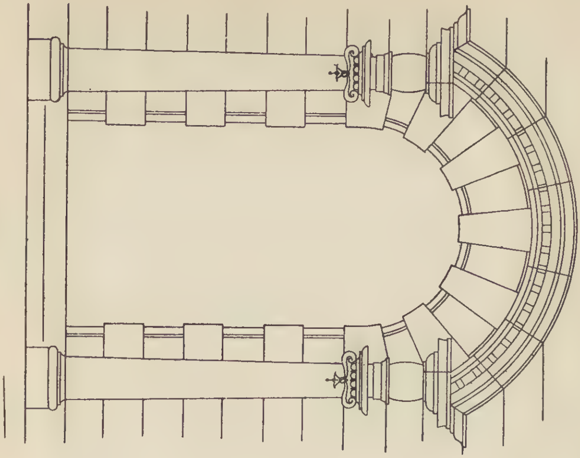
(139.) 65. Describe the construction, mode of driving, and advantages of concrete piles. (70.)

(140.) 66. A factory chimney shaft, octagonal on plan, and having an internal diameter of 6 feet, is to be erected 80 feet high above top of footings. Draw to a scale of 8 ft. to an inch a section of one wall from top to bottom showing the cap and the footings, and a plan of the shaft taken at a height of 30 feet from top of footings. Also, draw to a scale of $\frac{1}{2}''$ to a foot an enlarged section of one wall for a height of 15 feet above the footings showing the fire-brick lining, and state how high you would carry this. (80.)

(141.) *67. The diagram shows the party wall between two houses without basements in a terrace of uniform height. One house is to be pulled down and in its place a hotel is to be erected with a basement 12 feet below the original ground-floor level, and the party wall is to be carried up 20 feet above its original height. It is decided not to pull down the old wall but to underpin and thicken it. Draw to a scale of 4 feet to an inch a section from top to bottom of the wall when raised and thickened, including footings, hatching in the old portion, and figuring the total thickness at the various stages. Describe fully the precautions which you would take while doing the under-pinning. (80.)

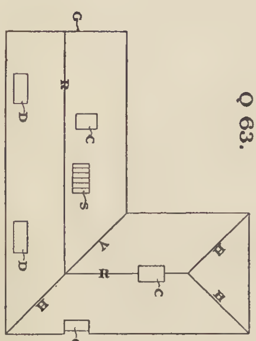
(142.) 68. Describe with sketches, the lighting, ventilating and heating of a ward containing six beds in a cottage hospital. (70.)

Stage 3 and Honours, 1906.



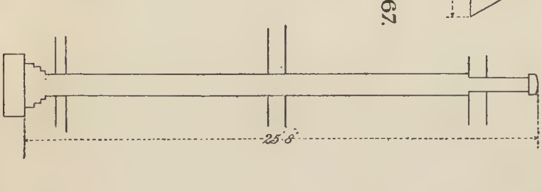
Q 52.

Q 44.



Q 63.

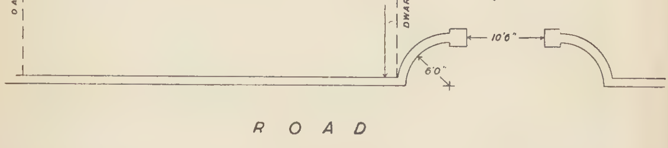
C.- *Chimney Stacks*
D.- *Flat top Dormer Windows.*
G.- *Gable End* R- *Ridge*
S.- *Skylight* H- *Hips* V- *Valley*



Q 67.

(143.) 69. Show by diagrammatic sketches what difference is produced in the bending moments of a beam continuous over three equal spans (*a*) when the three spans are uniformly loaded; (*b*) when one of the end spans is unloaded; and (*c*) when both the end spans are unloaded. (80.)

(144.) 70. What is meant by the term "modulus of elasticity"? Assuming the modulus of elasticity of wrought iron to be 26,000,000 lbs. per square inch, calculate the length of a tie-bar, 2 inch diameter, when loaded tensionally with 30 tons, if its length when unloaded was 20 feet. (80.)



Q. 145.

BOARD OF EDUCATION, SOUTH KENSINGTON.

SUBJECT III.—BUILDING CONSTRUCTION (HONOURS).

PRACTICAL EXAMINATION IN DESIGN AT SOUTH KENSINGTON.

(145.) A gate-keeper's lodge at the entrance to a private park with gate piers and ornamental oak entrance gates.

The block plan shows the entrance to the park, and also the site to be fenced off for the lodge. The accommodation required is:—On the ground floor: combined living room and kitchen, about 200 feet superficial area; scullery, about 150 feet superficial area, to have copper, sink, and small range: larder and pantry. The coal cellar and earth closet may be in the back yard. On the first floor 3 bedrooms separately approached, each with a fireplace. Drawings required:—Ground plan showing the whole of the site and position of outbuildings in yard: first floor plan: one section which must be taken through the staircase: two elevations, one towards road, and one towards the drive in park. All the above to a scale of 4 feet to an inch. Elevation to a scale of 2 feet to an inch of the gate piers and the gates, the latter to be of oak of an ornamental character. Inch-scale details of the living room window. The materials for the lodge and the piers may be either stone or brick, or a combination of each; picturesqueness of design is to be aimed at, and neatness of drawing will be considered in apportioning marks. The drawings to be in pencil.

State approximate cost, and how estimated.

THE ROYAL INSTITUTE OF BRITISH ARCHITECTS.

THE FINAL, JUNE, 1905.

Tuesday Morning: Three hours and a half.

III. THE NATURE AND PROPERTIES OF BUILDING MATERIALS: THEIR DECAY, PRESERVATION, AND QUALITY, AND THEIR APPLICATION IN BUILDING.

One hour and a half.

Hon. Examiners: { H. D. SEARLES-WOOD. A. H. KERSEY.

Candidates were not expected to attempt more than six questions.

(146.) 1. What are the materials you would employ in making foundations in the following soils? Give the tests you would apply in selecting each material and the weight per foot super you would put on each site:—(*a*) peat on the banks of a river, (*b*) gravel with runnings and, (*c*) wet clay, (*d*) chalk.

(147.) 2. What tests do you apply when selecting bricks? To what causes is the presence of free lime in bricks due? What effect has it on brickwork?

(148.) 3. What are the chief defects timber is liable to? Give a description of each, illustrated with sketches, and describe the best methods of preventing each.

(149.) 4. What are the principal divisions into which building stones are grouped? Give a list of three examples of each kind, arranged in order of strength, and the following particulars; (*a*) colour; (*b*) weathering; (*c*) method of dressing; (*d*) building where used; (*e*) purpose for which best suited.

(150.) 5. Give list of roofing materials arranged in order of cost, and the tests you apply in selecting each, the

method of laying, and least angle at which they can be laid, and the purpose for which each is best suited.

(151.) 6. Describe the most suitable materials for flooring the following: (*a*) Hospital ward; (*b*) shops; (*c*) factories; (*d*) stables; (*e*) dwelling houses. Give your reasons for selecting each, and the tests you would employ.

(152.) 7. What is the proper method of applying Dr. Angus Smith's solution, and how do you test ironwork coated with it? What other methods of treating metal to prevent rusting are you acquainted with, and for what purposes are they best suited?

(153.) 8. What is the best treatment for constructional ironwork to prevent rusting—(*a*) when it will be encased in concrete; (*b*) when it will be protected with terra cotta?

(154.) 9. What are the tests you would specify for Portland cement for the following purposes? Give your reasons for varying the tests in each case: (*a*) for concrete foundations under water; (*b*) for reinforced concrete; (*c*) for cement rendering on brickwork.

Maximum No. of Marks: 75.

IV. THE ARRANGEMENT AND CONSTRUCTION OF BUILDINGS IN RELATION TO HEALTH: Drainage, Water Supply, Ventilation, Lighting, and Heating.

Two hours.

Hon. Examiners: { Arthur Ashbridge. F. T. W. Goldsmith.

Candidates were not expected to attempt more than five questions, but all were to attempt the first.

(155.) *1. The accompanying plan comprises a town house (not detached), with a stable and coach-house in rear. Show on same how in your opinion the buildings should be drained. It is to be assumed that there is a sewer in the centre of the road in front of the house, also in centre of the roadway of the mews: see dotted lines on plan.

* This plan is not published.

(156.) 2. Draw section to $\frac{1}{4}$ scale through wall of house, showing soil-pipe with branches from w.c.'s, &c., also showing how the soil-pipe should be connected with the drain and how finished at the top. It is to be assumed that the house consists of six stories, and that there are w.c.'s in basement and on ground, first, and second floors.

(157.) 3. Draw section through wall of house to $\frac{1}{4}$ scale, showing waste-pipe, with pipes from baths, lavatories, &c. It is to be assumed that there is a sink in basement, also a lavatory basin on ground floor, also a lavatory basin and bath on the first and second floors.

(158.) 4. In building a hospital for infectious diseases, how many superficial feet of ward floor space would you allow for each patient; and how many cubic feet of ward space would you allow for each patient?

(159.) 5. If you were asked to convert an ordinary dwelling house into a private nursing home, what points would you take into consideration in determining which room should be used for the operating room? Having selected the room, what in your opinion would be necessary to be done to render it suitable from a sanitary point of view and otherwise?

(160.) 6. What are the principal systems of ventilation? State what you know of each.

(161.) 7. In building a stable with living rooms over, what precautions would you take to prevent the latter becoming contaminated by the former?

Maximum No. of Marks: 75.

V. SPECIFICATIONS, ESTIMATING, AND PROFESSIONAL PRACTICE.

Tuesday Afternoon; three hours.

Hon. Examiners: { A. BURNELL BURNELL. R. J. ANGEL.

(162.) 1. Write a complete specification in all trades for four ornamental stone gate piers, together with wrought and

hammered iron gates for the principal entrance to a gentleman's estate. The central opening for vehicles to be 12 feet wide, and the two side openings for pedestrian traffic to be 5 feet wide each. Give a rough sketch with figured dimensions.

(163.) 2. Write a specification for a timber-framed dome of an ornamental character, 30 feet diameter, covered with lead. The wall supporting the dome to be of stone.

(164.) 3. (*a*) Explain precisely the precautions you would take when preparing the conditions of contract to deal with the possibility of the contractor becoming bankrupt during the progress of the work.

(*b*) What do you understand by the expressions—"prime cost value" and "allow the sum of ——," as contained in a specification? Explain the difference between them.

(165.) 4. Specify the clauses of external plumbers' work for a well-built residence (say £3,000 to £4,000), the roof being tiled, having gables, dormer windows, lead flats, and bay windows with curved roofs.

Also specify the internal plumbers' work in connection with the baths, scullery and pantry sinks, w.c.'s, and specify the value you would allow for the various fittings.

(166.) 5. Write the clauses under joiners' work, for a staircase of a moderate-sized hotel, to be executed in hardwood, width 5 feet, and in three flights. The candidates can give rough marginal sketch to show their reading of the question to satisfy the examiner. Also write a short specification for the oak panelling round the hall of the said hotel, and also the hardwood flooring.

Maximum No. of Marks: 75.

Wednesday Morning: three hours and a half.

VI. CONSTRUCTION: Foundations, Walls, Retaining Walls, Arches, Vaults, Floors, Roofs, &c., and Constructive Details in all Trades.

Hon. Examiners: { Alfred Conder. George Hubbard, F.S.A.

Candidates were not expected to answer more than four questions, but all were to attempt the first.

(167.) 1. A one-story factory, 70 feet by 20 feet, is to be constructed with 14-inch brick walls upon a site which has a marshy subsoil capable of sustaining safely a weight of only 10 cwt. to the foot superficial. No firmer foundation is obtainable until a depth of 35 feet is reached. The factory is to contain a steam hammer weighing 5 tons, and delivering a blow equal to 10 tons.

Draw to a scale of 2 feet to 1 inch a section of the foundations of the building, constructed as inexpensively as would be safe, and show the special precautions necessary for the foundation of the steam hammer; also state how the building would be kept dry.

(168.) 2. The cellar of a house, 35 feet by 18 feet, the floor of which is 5 feet below the bottom of the sewer of the adjoining street, is flooded after a rainy season with water coming up through the brick floor to a height of 2 feet 6 inches. Show by sketches, and describe fully, the means which could be adopted to remedy the complaint.

Also show by sketches how the flooding could have been guarded against if it had been known before the building was commenced to what height the subsoil water was liable to rise, assuming that the levelsof the floors could not have been altered.

(169.) 3. Draw to scale, $\frac{1}{2}$-inch to a foot, elevation, section, and plan of the masonry for a window opening 12 feet by 8 feet, constructed in a stone building, and formed into three

lights with mullions and transoms, fitted with metal casements. The joints to be shown.

Sketch a detail section of the cill to a quarter full-size.

(170.) 4. The roof of a house made in one span and covered with plain tiles at an angle of 45° is to be supported upon substantial brick walls 40 feet apart from front to back, and to contain two stories, the rooms of which are to be lighted by dormer windows covered with lead. The floors are to be constructed with fir joists carried upon wrought-iron trusses, also supporting the roof timbers.

Draw to scale, 2 feet to 1 inch, a cross-section through the upper part of the building, showing the construction, and state the precautions to be adopted for guarding against variations of external temperature.

(171.) 5. A brick chimney-shaft containing 3 flues, each 14 inches by 9 inches, passes through a slated roof midway up the slope, with its longest side parallel to the ridge.

Draw to scale, 1 inch to a foot, all the details of the carpenters', plumbers', and slaters' work connected with this part of the building.

Draw to a scale of 1 inch to a foot a half-plan and a section of an octagonal lantern light, 8 feet in diameter, constructed with wood upon a lead flat, the height being 5 feet.

The lights to be hung at the top and to open outwards. The roof to be covered with lead.

Maximum No. of Marks: 100.

Wednesday Afternoon: three hours.

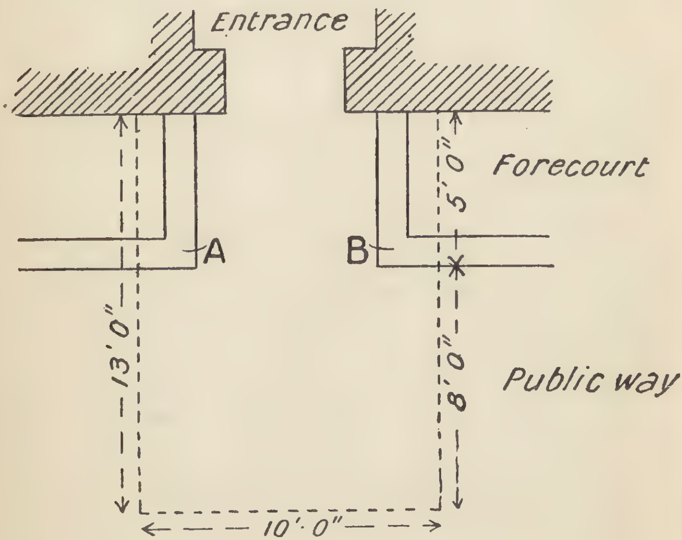
VII. CONSTRUCTION: Construction in Iron and Steel; Shoring, Underpinning, and dealing with Ruinous and Dangerous Structures.

Hon. Examiners: { Lewis Solomon. / W. E. V. Crompton.

(172.) 1. An iron and glass shelter is required over the entrance to a public hall; the width is to be 10 feet, and the total

projection 13 feet, of which 5 feet is over the forecourt and 8 feet over the public way. The structure is to be carried by cantilevers over the footway at a height of 10 feet, but columns can be placed at A and B. The area of metal in cantilevers to stand a maximum bending moment of 42 inch tons.

Make a sketch design in plan, section, and elevation to ½-inch scale, showing the shelter in relation to its sup-



ports at A and B and the forecourt railings, and with details of the construction to 1½-inch scale.

What system of glazing would you adopt, and why?

Explain the nature of the stresses in that part of the cantilever between A or B and the wall.

(173.) 2. A steel stanchion to carry 100 tons is fixed upon a cast-iron base, which in its turn rests upon a foundation of blue brick in cement: draw a detail of the whole to 1½-inch scale and give the working out of the various dimensions,

the safe working stress on steel in this case being taken at 2 tons per square inch.

Indicate by sketches any alternative method for forming a foundation to receive such a stanchion, and mention any advantages or disadvantages it may have compared with the first named method.

(174.) 3. Explain shortly what you know about reinforced concrete.

(175.) 4. If you were instructed to remove the buildings at the corner of two streets prior to rebuilding, explain in detail what precautions you would take to ensure the security of the various structures in view of the rebuilding, thus protecting your client's interests, that of the adjoining owners, and the safety of the public.

(176.) 5. In removing the above buildings you lay bare in a party-wall an oak story post of large scantling which runs up through two stories and receives large bressummers carrying each floor of the adjoining house. The post is rotten, and so are the bressummers for a length of 12 inches from the bearing on the post. Explain carefully what you would propose to do.

Maximum No. of Marks: 125.

THE ROYAL INSTITUTE OF BRITISH ARCHITECTS.

THE INTERMEDIATE EXAMINATION.

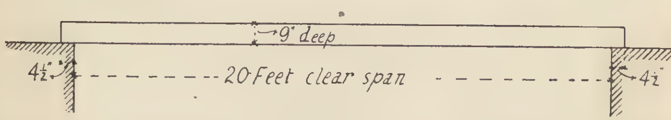
For Registration as Student R.I.B.A.

Morning Sitting, Wednesday, 13th June, 1906.

V. THEORETICAL CONSTRUCTION: STRESSES, STRAINS, AND STRENGTH OF MATERIALS. (From 10 a.m. to 12 noon.)

*** *Not more than six questions to be attempted.*

(177.) 1. The girder shown in sketch carries a distributed load of 1 ton to the foot run. Make any comments that occur to you upon the design of the girder and its supports. Sketch the general alterations, if any, that you consider desirable.



(178.) 2. How is the strength of a beam affected by alterations of (*a*) length, (*b*) width, and (*c*) depth?

(179.) 3. Give any formula you know for determining the strength of one of the following:—

(1) A plate girder of I section;

(2) A rolled steel joist;

(3) A rectangular wooden beam;

and work out an example in figures.

(180.) 4. Explain the difference between an "empirical" and a "rational" formula and state to which class belongs the formula you have given in answer to question No. 3.

(181.) 5. Make a diagram showing the stresses upon each member of a king-post truss for a roof 24 feet span and 30° pitch.

State the distance you assume from centre to centre of trusses, the weight per superficial foot you take in calculating the load, and what are the scales you use.

(182.) 6. Why is trouble sometimes experienced through the expansion of concrete in floors and flats, and what course would you adopt to reduce such trouble to a minimum?

(183.) 7. A cast-iron water-tank, 20 feet square on plan and 8 feet deep, made of metal which may be assumed to average 1 inch thick, is to be supported on nine piers, built of stock brickwork in blue lias lime mortar, and each 12 feet high. Give the total weight of the tank with 8 feet of water in it, and the size you would make the several piers. Disregard the tie rods and flanges of the tank, and also all questions of necessary girders.

(184). 8. What load per square inch would you allow in a strut of Baltic fir about 18 diameters long?

(185.) 9. What is a "factor of safety," and what figures would you use in dealing with steel girders and brickwork respectively?

Maximum No. of Marks: 75.

Afternoon Sitting, Wednesday, 13th June, 1906.

VII. ELEMENTARY APPLIED CONSTRUCTION: THE NATURE AND USE OF ORDINARY BUILDING MATERIALS. (From 2.30 to 5.30 p.m.)

(186.) 1. Describe and sketch:—
Four joints for flooring boards, bressummer, dragon-tie, secret gutter, soaker, throating, lap and gauge, Lewis.

(187.) 2. Where, and why, would you use the following?
Inodorous felt, pugging, cross-bridging, tile-creasing, asphalt, tar-paving.

(188.) 3. What materials would you consider best for the following? and give your reasons concisely.

A drain under a house, fire-proof partition, a wall to carry heavy loads, soil-pipe.

Give, in order of merit, the three different subsoils you consider best for building on.

(189.) 4. Stone is specified to be laid on its quarry bed. Give meaning of this, and reason. Also any exceptions you would make to this rule.

(190.) 5. Draw, to half-inch scale, plan, elevation, and section of a framed partition, 20 feet clear span and 10 feet high, to carry floor over. There is a doorway 3 feet wide and 7 feet high in centre of partition.

(191.) 6. The angle of a building is splayed 4 feet wide and corbelled out in stone, square over. Draw plans and sections, half-inch scale, showing construction. The floor to be level with top course of corbelling, and all walls are 18 inches thick.

Maximum No. of Marks: 125.

THE ROYAL INSTITUTE OF BRITISH ARCHITECTS.

THE FINAL EXAMINATION QUALIFYING FOR CANDIDATURE AS ASSOCIATE R.I.B.A.

Morning Sitting, Tuesday, 26th June, 1906.

III. THE NATURE AND PROPERTIES OF BUILDING MATERIALS: THEIR DECAY, PRESERVATION, AND QUALITY, AND THEIR APPLICATION IN BUILDING.

From 10 to 11.30 a.m.

*** *Not more than six questions to be answered.*

(192.) 1. Give a list of the different qualities of lime used for making mortar and the proportion in which each is mixed; state whether the proportions are measured before or after the lime is slaked. What difference in bulk does the slaking of each kind produce? What variation would you make in the proportions when a mortar mill was to be used?

(193.) 2. State the method of ascertaining the proportion of cement to aggregate in making reinforced concrete, and the reason why fineness improves the strength of cement. Describe briefly the process of making cement.

(194.) 3. Describe the methods of preparing the materials of which bricks are made, and the processes of wet (or slop) and dry (or Fletton) brickmaking. In what respect do the bricks produced by the two methods differ, and which do you prefer, and why, and for what purposes?

(195.) 4. Give a list of the qualities which you would require in a building stone (*a*) for a public building in a manufacturing city, and (*b*) for a country church.

(196.) 5. In a tabular form give a list of the different kinds of timber used in construction, arranged in order of strength.

Give the purposes each is best suited for, and the methods you adopt to see you get the qualities you specify.

(197.) 6. Give a list of the materials you would specify for floors, walls, and ceiling of an operating theatre selected for their non-absorbent qualities, and describe the method of laying or securing them, and the final treatment of the surfaces.

(198.) 7. Specify the different qualities of steel and cast iron you would use for a building of glass and metal, to be used as a winter garden, and the methods you would employ to check the quality and weight of the material when it is delivered on the site to ascertain that it was in accordance with the specifications in all particulars

(199.) 8. The painted stucco front of a high-class residence has got into bad repair. Specify the materials you would employ before repainting to make good the places that were blistered and to make up the surfaces when the outer coat had perished before the work was painted. What are the causes of blistering, and how are they avoided or remedied?

Maximum No. of Marks: 75.

IV. THE ARRANGEMENT AND CONSTRUCTION OF BUILDINGS IN RELATION TO HEALTH: Drainage, Water Supply, Ventilation, Lighting, and Heating.

From 11.30 a.m. to 1.30 p.m.

*** *Not more than five questions to be answered, but every Candidate must attempt Question No.* 1.

(200.) 1. The plan marked A is the basement floor plan of a detached London mansion. The basement floor is 11 feet below the level of outside ground, and the distance to main sewer is indicated on plan, as are the positions of the w.c.'s, baths, sinks, &c. Show by single lines the soil

and rain-water drains and pipes, manholes, gullies, &c., figuring the sizes of the pipes and manholes.

State what fall the soil and rain-water drains should have.

(201.) 2. Draw to $\frac{1}{4}$-inch scale a section through a manhole in area on N. side and an elevation of the soil, waste, vent and other pipes at that point, figuring dimensions and describing material.

(202.) 3. Draw to $\frac{1}{2}$-inch scale what in your opinion is the best form of

(*a*) Valve closet.

(*b*) Wash-down closet.

(*c*) Grease trap. Give the maker's names and a brief description in each case.

(203.) 4. What steps would you take to cure dry rot in the floors of a warehouse where the floors are of the usual wood, iron and concrete constructions?

(204.) 5. State what you know about the regulations of public authorities as to

(*a*) Open spaces at the rear of buildings.

(*b*) Internal areas.

(*c*) W.c.'s above and below ground level.

(205.) 6. What is the best aspect for dwelling-house, and why?

What measures should be taken in damp low-lying districts to ensure the sanitary condition of the building?

Maximum No. of Marks: 75.

Afternoon Sitting, Tuesday, 26th June, 1906.

V. SPECIFICATIONS, ESTIMATING AND PROFESSIONAL PRACTICE.

From 2.30 to 5.30 p.m.

(206.) 1. Write a specification for all trades for an asphalted flat roof over a hall 25 feet square to a public building, and provided with an octagonal dome, 15 feet diameter, glazed on all sides and finished inside with plaster enrichments.

(207.) 2. Write out fully the "*general* clauses" in a specification governing bricklayers', masons', carpenters' and joiners' work.

(208.) 3. State approximately the cost per cubic foot of a high-class residential building executed in—

(*a*) Brickwork with best quality red facings.

(*b*) Portland or other hard stone facings.

Also give the price per cubic foot of Portland or other hard stone worked as Ashlar.

(209.) 4. If you are acting for a client in rebuilding his premises, what are the points affecting him with regard to his neighbours' rights, and what precautions would you take to safeguard your client in the event of litigation ?

(210.) 5. Certain work is being executed in a building over and above that included in the contract. How would you exercise a control over it in the matter of the final settlement of accounts?

Maximum No. of Marks : 75.

Morning Sitting, Wednesday, 27th June, 1906.

VI. CONSTRUCTION : FOUNDATIONS, WALLS, RETAINING WALLS, ARCHES, VAULTS, FLOORS, ROOFS, ETC., AND CONSTRUCTIVE DETAILS IN ALL TRADES. (From 10 a.m. to 1.30 p.m.)

**** Not more than four questions to be answered, but all Candidates must attempt Question No.* 1.

(211.) *1. The accompanying illustrations show part of a dwelling-house fronting a main thoroughfare. Prepare $\frac{1}{4}$-inch scale drawings showing how you would convert the dwelling-house into a shop. The ground floor must be 14 feet high, having properly ventilated shop front with roller shutters and stall-board lights.

The basement to be 12 feet high, continued under the street pavement, and to be well lighted, ventilated and

* This illustration is not published.

dry, the sub-soil water-level being 9 feet below the street pavement level.

Also prepare 1 inch scale drawings of details, and briefly describe the materials used.

(212.) 2. Draw ½ inch scale plans, sections and elevations with templates, showing all stone jointing of Gothic vaulting, piers and window, to one bay of an aisle, as illustrated by the accompanying plan. Describe briefly the principles of the construction. Only half the window and a quadrant of the vaulting need be shown in detail.

(213.) 3. What is reinforced concrete? State its principles of construction, and show by rough sketches its application to floors, walls, roofs, piers, and retaining walls.

(214.) 4. Draw to ½ inch scale a plan and section of a wooden gallery, 40 feet wide by 20 feet deep, to a church. No constructional ironwork to be used, and all dimensions of the various parts are to be given.

(215.) 5. Draw to ½ inch scale a plan of a lead flat over an out-building, 20 feet by 15 feet, enclosed on three sides by parapet walls. The fourth side is the flank wall of the main building. The only connection to the drain is through a manhole opposite the centre of the 20 foot external wall. Give a section through the flat and through the gutter, and state the weights of lead you would suggest.

Maximum No. of Marks: 100.

Afternoon Sitting, Wednesday, 27th June, 1906.

VII. CONSTRUCTION: CONSTRUCTION IN IRON AND STEEL; SHORING, UNDERPINNING, AND DEALING WITH RUINOUS AND DANGEROUS STRUCTURES. (From 2.30 p.m. to 5.30 p.m.)

(216.) 1. (*a*) There is a row of warehouses, 50 ft. deep, out to out, and fifteen feet frontage, centre to centre, each. It is desired to unite the centre pair on *the ground floor* by the removal of the party wall which carries the 14 inch

thick brick wall over and insert steel girders in lieu of the wall, the girders carried on stanchions. The warehouses consist of ground floor 12 feet high, first and second floors 10 feet high each, all floor to floor, and the top or third floor 9 feet high in clear. The floors in all cases are carried on 9 inch by 3 inch wooden joists running from party wall to party wall, and the roof is of 10-inch of concrete (average thickness) covered with asphalt. The parapet between the buildings is 3 feet above the top of the asphalt. Sketch section of party wall and girder to $\frac{1}{4}$ inch scale.

(*b*) Assuming the party wall a sound one, how do you proceed to remove the ground floor wall? Give sketches explanatory of the work to be done.

(*c*) What is the total weight the girders will have to carry, assuming the warehouse floors have to bear a weight safely of $2\frac{1}{2}$ cwt. to the foot, including the floor itself?

(*d*) The girders rest on the front and back wall at either end, and on two stanchions between the external walls, forming three equal openings between the front and back walls. Give one quarter full size section of girders, and figure the dimensions.

(*e*) Calculate the horizontal plan and section of each stanchion. Draw same quarter full size figuring all parts. State whether you intend the stanchion to be steel or cast iron in your sketch.

(*f*) Draw to quarter full-size elevation of the head of the stanchion, and elevation of the girders immediately over one stanchion: the girders to be in three lengths, meeting over the heads of the stanchions.

(*g*) If the front wall is at all insecure from bulges or cracks, how would you support it during the insertion of the girders, and afterward?

Maximum No of Marks: 125.

SEPTEMBER, 1900.

WAR OFFICE ASSISTANT SURVEYORS' EXAMINATION.

Use and Properties of Materials.

(Only EIGHT of the following questions are to be answered.)

(217.) 1. For what purpose is sand added to lime in the preparation of mortar?

(218.) 2. Which of the following materials is most suitable for use as an aggregate in Portland cement concrete where great strength is required, viz.:—Blue Guernsey granite, Bath stone, blue Staffordshire bricks, Portland stone, broken fire-clay pipes? Place these aggregates in their order of merit, and give the reasons for your selection.

(219.) 3. How would you distinguish between crown, plate, and sheet glass? Describe the method of manufacturing each kind of glass.

(220.) 4. Give examples of igneous and aqueous rocks used in building, and state which are most useful to the builder.

(221.) 5. What is "quarry sap"? How does it affect the working?

(222.) 6. Give the weight and thickness of metal in the following lead pipes, viz.:—½ inch water service for 30 lbs. pressure, 2 inch waste, 4 inch ventilator.

(223.) 7. What is the difference between red, yellow, and white Baltic timber? For what purposes is each kind used?

(224.) 8. How is Roman cement made? What are its properties? For what purposes is it generally used?

(225.) 9. What is terra cotta? How is it manufactured? What are its principal uses in building?

(226.) 10. Why are rich limes slaked before use?

DRAWING (A).

Details of Construction (including Theory of Construction) in Engineering Works.

The Candidate is to attempt six and not more than six of the following questions, and when drawings are necessary for illustration they are to be sketches only, and not

finished drawings. Three of the questions must be selected from the first six.

(227.) 1. A plate girder 30 feet clear span, 3 feet deep and supported at each end, has top and bottom flanges consisting of two angles $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{5}{8}''$ and one plate $12'' \times \frac{5}{8}''$; assuming the unit stress to be 6 tons per square inch on the gross sections, what load will the girder carry at the centre?

(228.) 2. Suppose the above girder (question 1) were loaded with three loads of 4, 9 and 12 tons spaced equidistant from each other and the ends, draw the diagram of bending moments and shearing stresses, assuming the girder to weigh 4 tons.

(229.) 3. Ascertain the moment of resistance of a rectangular bar 4 inches deep and 2 inches wide, and the load it wil safely bear at the centre when placed on bearings 6 feet apart, the unit stress of the material being assumed at 6 tons per square inch.

(230.) 4. Draw the stress diagram of the following roof truss, the amount and direction of the loading being as shown in fig. 1, the direction of the reactions being indicated by the arrows.

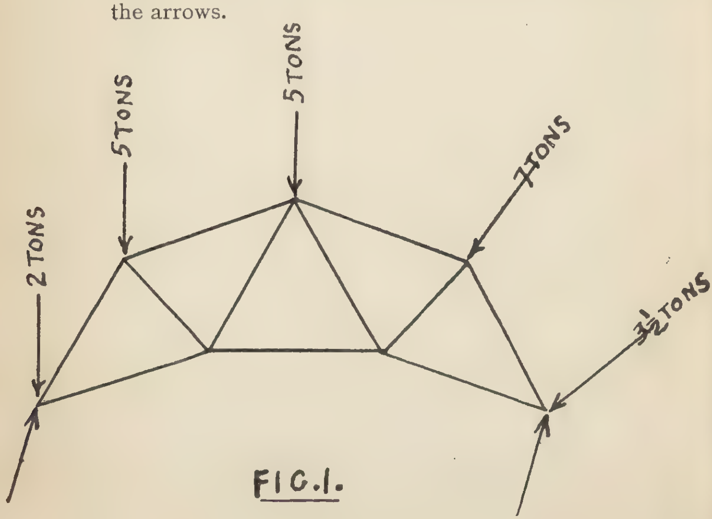


FIG. 1.

(231.) 5. How do you ascertain the radius of gyration of a column? Give an illustration.

(232.) 6. Sketch any voussoir of a segmental arch, and show the forces which keep it in equilibrium.

(233.) 7. Sketch the shoe of a roof principal with—

(*a*) Timber rafter and circular iron tie bar.

(*b*) Tee iron rafter and flat iron tie bar.

(234.) 8. Sketch and dimension a cast iron mooring post suitable for a dock wall, and show how it is secured.

(235.) 9. Sketch and dimension the vertical section of a 12 inch sluice valve suitable for a 500 feet head of water.

(236.) 10. Sketch and dimension the expansion rollers for the bearings of a bridge girder, say 250 feet long and weighing 120 tons.

(237.) 11. Sketch and dimension a pedestal or plummer-block suitable for the bearing of a shaft 9 inches diameter.

(238.) 12. Sketch and dimension the shoring you would adopt in excavating a trench 12 feet deep and 6 feet wide in loose material.

Sanitary Engineering.

(Only EIGHT of the following questions are to be answered.)

(239.) 1. How can water be raised from deep wells by means of compressed air without the aid of pumping machinery? Illustrate your answer by a sketch.

(240.) 2. A sewer has to be laid through quicksand overlying coarse gravel; how would you proceed with the work? What precautions should be taken to ensure its permanent stability?

(241.) 3. Compare from a hygienic point of view the conditions existing in towns having unventilated sewers, like those in Bristol, with towns having fully ventilated sewers, and untrapped gullies and house drains, like those in Paris; and with towns having partially ventilated sewers and drains, like those in London.

(242.) 4. Describe the meanings of the following terms used in Sanitary Engineering, viz.:—Septic, aerobic, and anaerobic treatment of sewage.

(243.) 5. Describe a method of transmitting sewage sludge containing 7 per cent. of solids, a distance of, say, half a mile, with a total lift of 50 feet.

(244.) 6. Tanks capable of holding a thousand cubic yards or sludge containing 10 per cent. of solids have to be altered to hold the same quantity of solids with 96 per cent. of liquids. State the capacity required.

(245.) 7. Show by sketches (not to scale) and describe five distinct forms of water-closets. Explain their good and bad points.

(246.) 8. Describe the "Plenum" system of ventilating buildings.

(247.) 9. Describe a method or methods of joining a stoneware closet out-go to a lead soil pipe and to an iron soil pipe; of joining a lead soil pipe to an iron soil pipe, and of joining a lead soil pipe and an iron soil pipe to a stoneware drain.

(248.) 10. What are the most suitable materials for scullery sinks? Show by a sketch, not to scale, a good and a bad method of draining a sink.

Drawing (B).

Details of Construction (including Theory of Construction) in Architectural Works.

The Candidate is to attempt six and not more than six of the following questions, and, when drawings are necessary for illustration, they are to be sketches only, and not finished drawings. Three of the questions must be selected from the first six.

(249.) 1. State Gordon's formula for columns, and ascertain the breaking load of a cast-iron column, 12 feet long, 10 inches external diameter, with $\frac{3}{4}''$ metal.

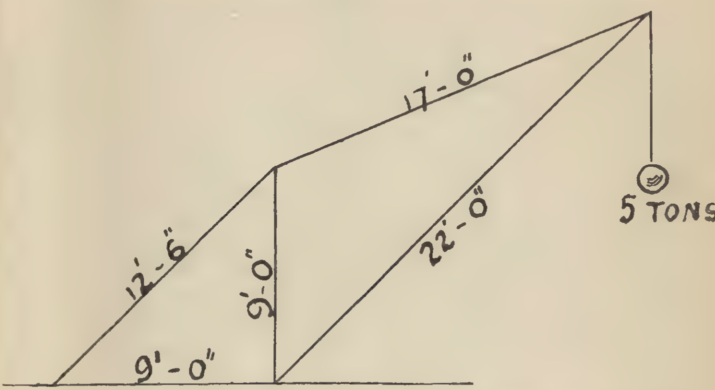
(250.) 2. Sketch a retaining wall, 12 feet high, the face having a batter of 1 in 12, suitable for retaining sand, and show the forces which keep it in equilibrium.

(251.) 3. A square chimney, 100 feet high, 6 feet wide at the base and 4 feet wide at the top, has to withstand a wind pressure of 56 lbs. per square foot; what must be the

average thickness of the brickwork, assuming the chimney to be simply resting upon and not attached to its base? Assume the bricks to weigh 120 lbs. per cubic foot.

(252.) 4. What is the modulus of elasticity of a material, and how do you ascertain it?

(253.) 5. Draw the stress diagram of the following crane:—



(254.) 6. Supposing the above crane (question 5) to be made wholly of timber, give the scantlings of the various members, showing how you arrived at them.

(255.) 7. Sketch the foot of a timber roof having a tiled covering, showing the connection to the wall of the building, the gutter, parapet wall, tiles, etc.

(256.) 8. Sketch three different kinds of covering for roofs, showing clearly how each is laid.

(257.) 9. Sketch three different plans for watertight glazing, suitable for a large building, consisting principally of iron framing and glass.

(258.) 10. Sketch the framing of the skylight of a timber roof, showing clearly how the joints are made weather-proof.

(259.) 11. Sketch three different joints for timber suitable for joints in tension.

(260.) 12. Sketch the vertical and horizontal section through a window having cased frames with double-hung sashes.

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